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A PRELIMINARY ANALYSIS OF TF34-100/400 JET ENGINE REWORK DATA I--ETC(U)

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A PRELIMINARY ANALYSIS OF TF34-100/400 JET
ENGINE REWORK DATA IN SUPPORT OF THE
MRP SYSTEM IMPLEMENTATION AT NARF ALAMEDA

by

Ernest R. Slaybaugh

December 1981

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A Preliminary Analysis of TF34-100/400 Jet Engine
Rework Data in Support of the
MRP System Implementation at NARF Alameda

by

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the
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ABSTRACT

The Naval Air Rework Facility (NARF) located at Naval Air Station (NAS) Alameda is in the process of implementing a Material Requirements Planning (MRP) system which will incorporate an inventory model to help manage those repair parts which are not always replaced during component rework. This thesis focused on analyzing TF34-100/400 jet engine rework data as one phase of that implementation. In particular, probability of replacement values were generated for the repair parts from demand data and the rework schedule during 1980, and the engine's bill of materials. In addition, a parametric analysis was conducted to study the optimal relationship between the shortage and surplus costs of the proposed inventory model for the TF34 repair parts. The analyses highlighted the importance of determining the actual shortage costs resulting from a work stoppage and suggested some potentially useful forms for the surplus cost parameter.

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ABBREVIATIONS

APA	Appropriated Purchase Account
BOM	Bill of Material
DHF	Demand History File
DTE	Development Test and Evaluation
I	Holding Cost Rate
MRP	Material Requirements Planning
MIS	Management Information System
NALC	Naval Air Logistics Command
NARF	Naval Air Rework Facility
NAS	Naval Air Station
NMDL	Navy Management Data List
NSA	Navy Stock Account
NSC	Naval Supply Center
NSN	National Stock Number
RFI	Ready for Issue
RSS	Ready Supply Store
SMIC	Special Material Identification Code
UAF	Units of Application File
UICP	Uniform Inventory Control Program

I. INTRODUCTION

The NARF located at NAS Alameda, California has been in the process of instituting an MRP system. The first phase of the following two-step implementation plan is being utilized to acquire expertise with the basic MRP framework and to build demand history files prior to incorporation of the target system [Ref. 1].

1. Implementation of a temporary system that will run on existing equipment and will be used to gain experience with the system and build up the necessary data file. This phase will include the design of the target system.
2. Implementation of the final system of the new computerized material handling equipment system.

The MRP system is intended to increase the efficiency of the rework process by reducing the number of work stoppages caused by stockouts. The quarterly supply support requirements can be projected by demand forecasting based on the planned quarterly workload schedule. The optimum inventory levels can then be determined from consideration of the costs of shortages and surpluses. Unfortunately, these costs are difficult to obtain. In absence of their actual values, implicit values can be developed by postulating values and examining the resulting values of safety and surplus stocks. From showing these latter values to decision makers, acceptable levels can be obtained and the

implied cost then determined by solving for the values which correspond to acceptable levels.

A. PURPOSE

The intent of this report is to begin this process by examining TF34 jet engine requisitions and generating replacement probability factors. This information is then used with stock cost projections in a proposed Repair Parts Inventory Model [Ref. 2] to determine the level of safety stock which results.

B. SCOPE OF ANALYSES

A TF34 jet engine Demand History File (DHF) which encompassed four consecutive quarters was provided by NARF Alameda. This file was subdivided into five categories based on service application and degree of repair necessary to certify a specific engine as Ready for Issue (RFI).

The main criteria for classifying an engine repair is the depth of disassembly that is required. The disassembly of the engine begins with the exhaust section. The repair process then proceeds through the turbine, combustion, and finally compressor sections. The removal/non-removal of the compressor section is what normally designates the engine repair as major or minor respectively. The Development Test and Evaluation (DTE) classification was assigned by the U.S. Air Force. It is used to identify approximately 20 lead

TF34-100 engines which are used for program development.

Table 1 lists the five categories.

A second file was also obtained which contained the repair parts units per application per specific engine model. The individual line items were verified against the Navy Management Data List (NMDL) in respect to unit price, unit of issue, and cognizance code. Only National Stock Number (NSN) items were utilized to ensure accurate pricing information. Additional emphasis was centered on stock items that are Navy Stock Account (NSA) parts. Demands concerning requisitions submitted on part number identified items were not included.

TABLE 1
TF34 Engine Repair Categories

Service	Engine/Model	Repair
Navy	TF34-400	Minor
Navy	TF34-400	Major
Air Force	TF34-100	Minor
Air Force	TF34-100	Major
Air Force	TF34-100	DTE

C. PREVIEW OF ANALYSES

Chapter II identifies the characteristics of an MRP system as applied to a rework-oriented process and reviews the proposed Repair Parts Inventory Stocking Model. Chapters III and IV contain presentations of the historical demand

data and the effects of utilizing the proposed Repair Parts Inventory Model. The major factors that should be considered in selecting the standard variables to be utilized are discussed. The Summary, Conclusions, and Recommendations are presented in Chapter V.

II. PROPOSED INVENTORY STOCKING METHOD

A. BACKGROUND

When manufacturing a product it has historically been difficult to have the correct number of parts ready at the right time. The technique known as MRP was developed in an attempt to resolve this problem. However, for complex products the extent of planning and paperwork required for a MRP system was considered to be unmanageable prior to the introduction of Management Information Systems (MIS) [Ref. 3]. The growth of MRP has therefore corresponded to the increase in the use of computer systems. The major objective of MRP is to acquire control over the inventory levels while simultaneously assuring that desired service levels are satisfied [Ref. 4].

B. MRP CONCEPT

The inputs to the MRP logic package consist of the Master Production Schedule, Bill of Materials (BOM), and the Inventory file. Finite quantities of the parts required to assemble n units of a product are generated based on their dependence to the production schedule. Figure 1 exemplifies a level-by-level explosion of the product structure as stated in a BOM.

At each level the computed requirements are compared against the available inventory, work-in-process, and planned

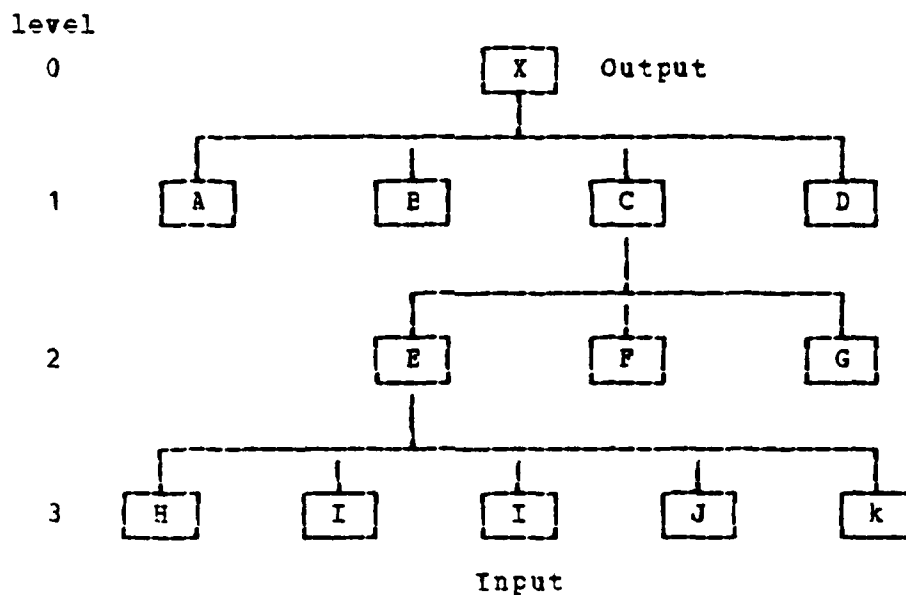


Figure 1: Traditional MRP Product Structure

requirements. When the lowest level, as determined by the BOM, is reached for a given part the time-phased net requirements are computed. The gross requirements for a part which is used for more than one end product are then accumulated and utilized for ordering purposes.

The MRP logic as applied to a rework process will be instituted at NARF Alameda with the implementation of the computerized inventory system. The rework process is initiated with the induction of a Non-RFI repairable asset (A BOM will be created by the NARF the first time an asset is inducted into rework). The asset will transition through

the stages of disassembly, repair, assembly, and testing prior to RFI certification. The depth of the product structure for each asset will depend on the degree of disassembly required to effect repair. The product structure of a repair process is presented in Figure 2.

A disposition code from Appendix A will be assigned at each level in the disassembly phase [Ref. 5]. To facilitate the understanding of this code, the TF34 engine will be used as an example. Because of external factors, the material condition of individual TF34 jet engines being inducted for repair can be different. Therefore, the disposition codes assigned at a specific level may differ from engine to engine. A repair part identified as "E" may be assigned a disposition code of "L" (leave on) during the repair cycle of one TF34-400 engine and a code of "R" (Rework) on a second TF34-400 engine. One or more of the repair parts identified as H, I, J, and K would then be required from the Ready Supply Store (RSS) to repair the second engine but not the first.

C. DEMAND DISTRIBUTION

NARF Alameda's production schedule is decided upon at a quarterly workload conference between NARF and Naval Air Logistics Command (NALC). The schedule, at least at the engine level, can be assumed to be independent from quarter to quarter. The demand of repair parts always replaced during

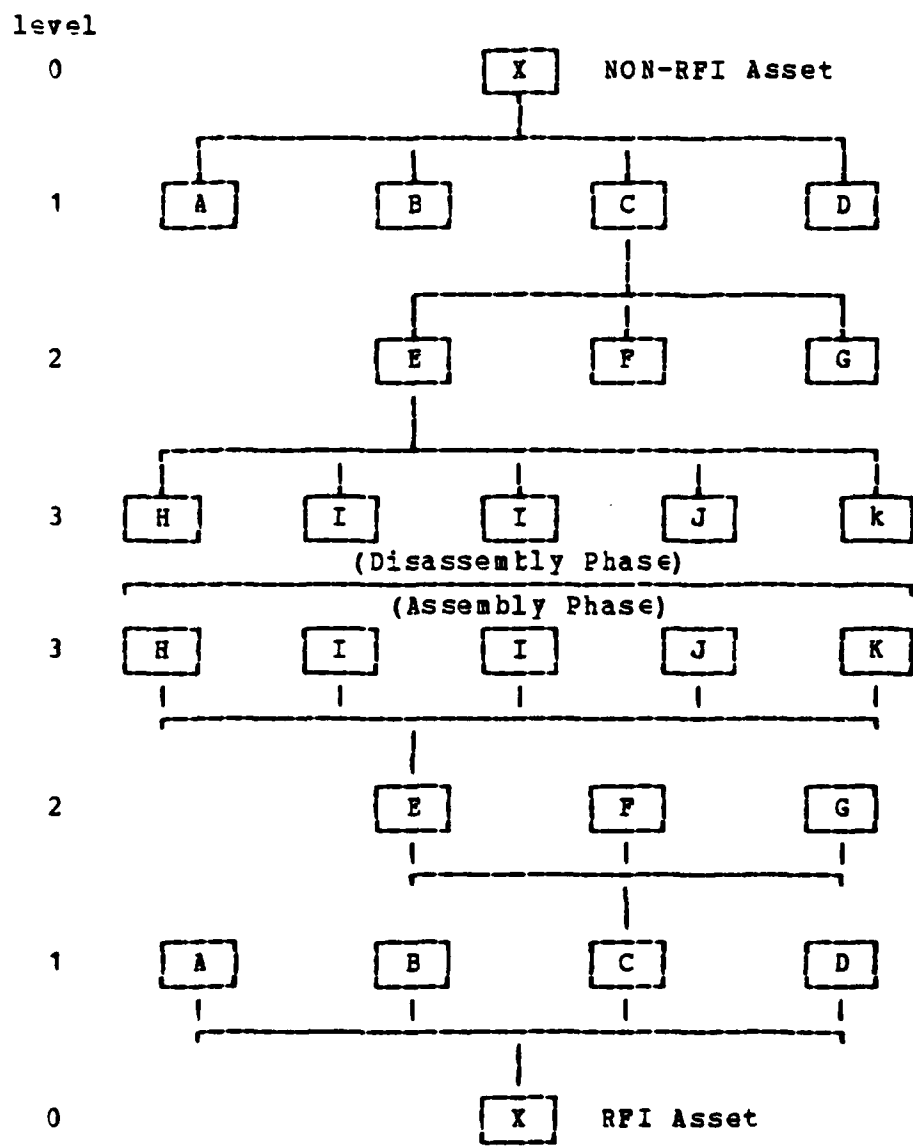


Figure 2: NARF MRP Product Structure

a repair cycle is dependent upon the production schedule. Once the schedule is established, the numbers of such parts and the time when they will be needed are known. If the replacement of a repair part is less than 100% then the demand will be a random variable dependent upon both the production schedule and the reliability of the part. With each engine induction for rework the decision as to replacement or non-replacement of such a repair part can be considered to be a Bernoulli trial [Ref. 6]. As such, the probability associated with replacement can be denoted as the parameter "P" and the "Reliability" or non-replacement as "Q" where $Q = 1 - P$.

A quarterly production schedule of n engines creates a demand for such a part which is a random variable. This variable can be modeled by the binomial probability distribution. The probability $p(x)$ of a total demand for x units of the repair part during a quarter can be expressed by [Ref. 7]:

$$p(x) = \frac{n!}{x!(n-x)!} P^x Q^{(n-x)} \quad (1)$$

where: $x = 0, 1, 2, \dots, n$

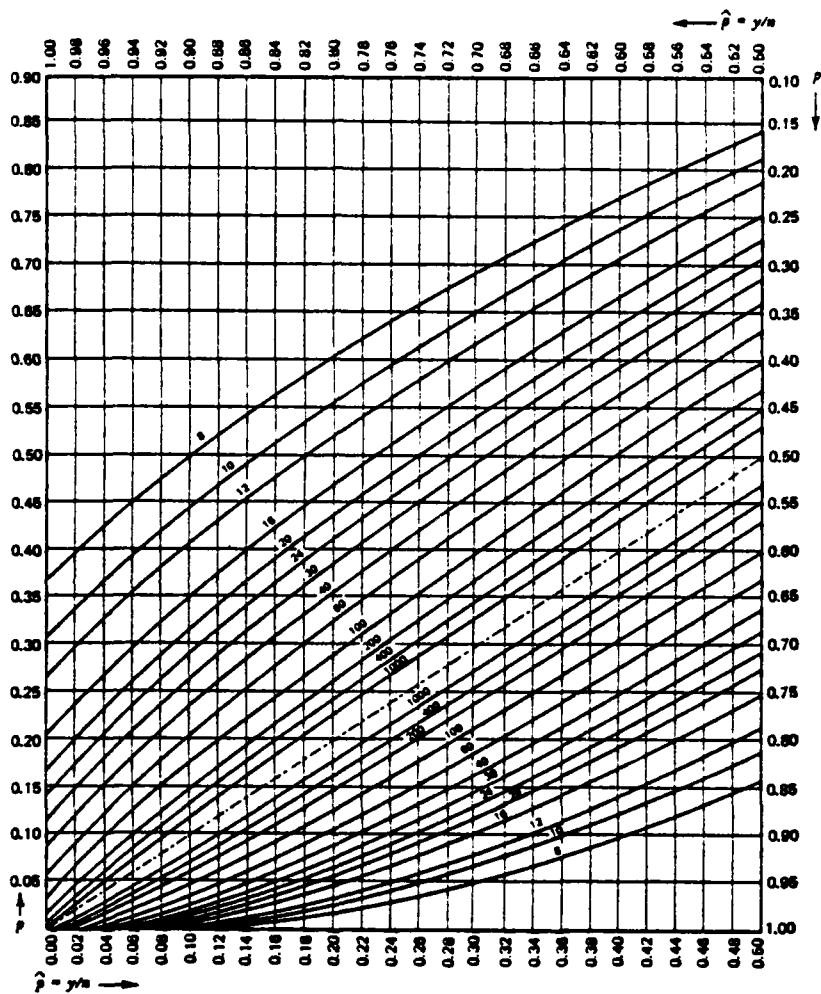
The mean and variance of this distribution are nP and nPQ , respectively. If the units of application m are greater

than one per engine, equation (1) can be modified to:

$$p(x) = \frac{nm!}{x!(nm-x)!} P^x Q^{(nm-x)} \quad (2)$$

where: $x = 0, 1, 2, 3, \dots, nm$

The population probability of replacement "P" values were estimated by using the DHF and Units per Application File (UAF) in conjunction with the historical induction schedule. Engine data spanning the entire four-quarters time period was used to provide the largest sample size and hence the minimum standard error of estimate. A 95% confidence interval for the population mean can be established from Figure 3 [Ref. 8]. The effects of sample size and the value of the P estimate on the confidence interval can easily be seen from Figure 3. As sample size increases the confidence interval is reduced; the widest interval for any sample of size n will occur for P equal to 0.500. For example, if P is estimated to be 0.55 based on a sample of 20 then the reader should locate the two curves labeled n = 20, and see where they contain the vertical line through p = 0.55. This approximates the confidence interval of P, which is: $0.31 \leq P \leq 0.58$. If n is increased to 1000, the 95% confidence interval is reduced to $0.52 \leq P \leq 0.58$.



* The numbers printed along the curves indicate the sample size n . If, for a given value of the abscissa y/n , p_A and p_B are the ordinates read from (or interpolated between) the appropriate lower and upper curves, then $\Pr(p_A \leq p \leq p_B) \approx 0.95$.

Figure 3: 95% Confidence Interval for P

D. PROPOSED INVENTORY MODEL

When the probability of replacement is less than 100%, the amount of inventory to stock is not obvious. If n is stocked there is a good chance that a surplus will exist at the end of the quarter after the scheduled rework is completed. If, on the other hand, a very small fraction of n is stocked there is a good chance that the scheduled rework cannot be completed due to a shortage of repair parts. The optimum level to stock should be a balance between these two extremes.

A logical framework in which to develop this balance is to consider the costs associated with shortages and surpluses. A surplus would be associated with money tied up in items which could have been spent on other parts for that quarter or the next. A shortage could result in a work stoppage until the part could be located elsewhere in the supply system with a corresponding delay in the availability of the reworked engine to the fleet.

A method to balance these costs is presented by McMasters [Ref. 9]. The model is a function of the following cost parameters.

1. Processing Cost - If C_p is the cost per unit which is incurred to place a repair part into the RSS, then the total cost of y units is C_p times y .
2. Holding Cost - If C_h is the cost per unit held per quarter then the total cost of y units is C_h times y , if the cost is assumed to be incurred

regardless of the length of time the item is in storage during the quarter. This assumption is reasonable since the storage space needed must be large enough to hold the entire quantity y of a repair part for some part of the quarter.

3. Shortage Cost - The shortage cost is representative of the time delays associated with submitting a requisition to the Naval Supply Center (NSC) Oakland when the NARF experiences a stockout. If C_s represents the shortage cost per unit and the demand x for a repair part during the quarter exceeds the inventory level y in the RSS then the shortage cost will be $C_s(x - y)$.
4. Surplus Cost - The unit cost of a surplus can be considered to be the product of the unit purchase cost " C :" of a repair part and a risk factor " K ." The value of K can range from zero to infinity. The risk factor should be minimal if the near future production schedules are expected to absorb any excess stock. The surplus cost when x is less than y is then the product $KC(y - x)$.

The expected total cost per quarter associated with stocking a quantity y of a given repair part is the sum of the costs listed above weighted by the probability $p(x)$ that x will be demanded during the quarter. It is described mathematically by equation (3).

$$EC(y) = (C_p + C_h)y + \sum_{x=0}^y KC(y - x)p(x) + \sum_{x=y+1}^n C_s(x - y)p(x) \quad (3)$$

when $p(x)$ is given by equation (1).

E. OPTIMAL INVENTORY LEVEL

The optimal order quantity of a specific repair part minimizes the expected total costs $EC(y)$. Using finite differences, the optimal inventory level y is the largest value of y for which

$$\bar{F}(y) > \frac{C_p + C_h + KC}{C_s + KC} . \quad (4)$$

where
$$\bar{F}(y) = \sum_{x=y}^n p(x)$$

and $p(x)$ is given by equation (1).

Determination of the optimal order quantity y is illustrated by the following example. Assume that the demand for a repair part is binomial and that it has the following parameters.

$C_p = \$1.00$	$K = 1$
$C_h = \$0.10$	$n = 10$
$C = \$250.00$	$m = 1$
$C_s = \$20.00$	$\hat{p} = 0.70$

Then the optimal level is the largest value of y for which

$$\bar{F}(y) > \frac{C_p + C_h + KC}{C_s + KC} = \frac{1.00 + 0.10 + (1)(250.00)}{20.00 + (1)(250.00)} = 0.93$$

and
$$p(x) = \frac{10!}{x!(10-x)!} (0.7)^x (0.03)^{(10-x)}$$

where $x = 0, 1, 2, \dots, 10.$

To solve this problem we need to compute

$$P(y) = \sum_{x=y}^{10} p(x)$$

for several values of y . First, realize that

$$P(y) = 1 - P(y-1) = 1 - \sum_{x=0}^{y-1} p(x)$$

Next we can make use of a recursion equation for computing $p(x)$.

From equation (1) it is easy to show that:

$$p(x) = \begin{cases} Q^n & \text{for } x=0 \\ \frac{(n - (x - 1))P}{x Q} p(x - 1) & \text{for } x > 0 \end{cases}$$

Table 2 provides the details of the computations needed to determine the optimal quantity y . It can be seen that

0.93 is between 5 and 6 units. Therefore the optimal quantity y is equal to 5 which is less than the expected demand nmP of 7.

TABLE 2
Table of $P(y)$ for Example

x	$p(x)$	y	$P(y - 1)$	$F(y)$
0	5.90×10^{-6}	0	0	1.000
1	1.37×10^{-4}	1	5.90×10^{-6}	1.000
2	0.00440	2	1.43×10^{-4}	1.000
3	0.00896	3	0.0016	0.998
4	0.03658	4	0.0105	0.989
5	0.14630	5	0.0471	0.953
6	0.40600	6	0.1934	0.806

III. ENGINE REPAIR ANALYSIS

This chapter will present a discussion of estimated P values and their relationship to the demand, Line items, and unit cost. Cost projections based on maintaining the inventory level at the expected demand or mean, first and second standard deviations above the mean, and 100% level are presented.

A. ENGINE INDUCTION SCHEDULE

The data on the TF34 engine repair was obtained from NARF Alameda for the calendar year of 1980. A total of 93 engines were inducted into rework throughout the year. It was assumed that an engine was certified as RFI in the same quarter that it was inducted for rework. In addition it was assumed that the repair classification of a specific engine did not change from the scheduled induction date throughout the rework process. A breakdown of the induction schedule by engine model and type of repair is presented in table 3.

The 62 TF34-400 minor repair inductions accounted for approximately 67% of the rework schedule. The four TF34-100 major repair actions accounted for less than 5% of the total TF34 engine induction schedule.

A quarter-by-quarter comparison of the scheduled inductions is indicative of a typical changing workload for

TABLE 3
TF34 Induction Schedule

Repair Category	FY 80-81				Total
	2	3	4	1	
TF34-400/MIN	17	15	22	8	62
TF34-400/MAJ	2	3	3	2	10
TF34-100/MIN	3	1	4	3	11
TF34-100/MAJ	1	2	1	0	4
TF34-100/DTE	2	2	2	0	6
Total	25	23	32	13	93

the NARF. The greatest number of inductions occurred in the fourth quarter of 1980 with 32 engines reworked. A 40% increase or 9 engines was experienced from the third to the fourth quarter in FY80. A subsequent decrease of almost 60% or 19 engines can be noted at the beginning of FY81. The normal inventory stocking models which forecast future demands solely on historical usage cannot anticipate such production variances.

B. APPLICABILITY/DEMAND DATA FILES

The UAF encompassed 3385 separate line items (which were ordered according to NSN). A sample file record identifying an item by Part Number, Cognizance Code, NSN, Special Material Identification Code (SMIC), Nomenclature, and Units of Application is presented in Appendix B. It should be noted that a SMIC code SN means that the component was

applicable to either engine model. A SMIC code of TB identifies a part as being peculiar to the TF34-100 engine.

The DHF consisted of approximately 1588 records grouped with respect to engine model and type of repair. Each record contained the total demand that was generated for a specific quarter. A sample of the DHF, listing the Cognizance Code, NSN, Engine Model, Type of Repair, Quarter, Unit of Issue, Total Demand, Total Requisitions, and Unit Price is presented in Appendix C.

Demands for both NSA and Appropriated Purchase Account (APA) repair parts were included in the DHF. The APA items were deleted for the purpose of this analysis. A total of 602 NSA line items were required to support the TF34 rework program. A summary listing of the number of items required to support the individual repair categories is presented in Table 4.

A logical assumption would be that as the depth of repair increases there should be a corresponding increase in the number of line items required for support. A second assumption would be that the number of line items required for a similar depth of repair should be approximately the same for either engine. The data presented in Table 4 contradicts such assumptions. Although there is an increase in line items from a minor to a major for the TF34-100 engine, the 400 engine shows a marked decrease from 364 to 274 items.

TABLE 4
TF34 Engine Repair Parts per Repair Category

Category	Cognizance Code					Total
	1R	9C	9J	9V	9Z	
100-DTE	28	5	0	9	1	43
100/MIN	79	4	0	45	2	130
100/MAJ	113	14	0	45	10	182
400/MIN	289	21	1	15	38	364
400/MAJ	223	19	1	3	28	274

There is also a large difference in the number of items required for the same level of repair. The TF34-400 utilized 364 items for a minor repair; whereas the TF34-100 required only 130. The same pattern can be seen in the major rework of the TF34-100/400 engines. The apparent contradiction to the above assumptions could be a result of maintenance personnel ordering parts against one engine which includes anticipated usage on expected future engines.

C. PROBABILITY OF REPLACEMENT (P) VALUES

The probability of replacement values was calculated as follows:

$$\hat{P} = \frac{D}{UA * N}$$

where D is the total demand over the four quarters, UA is the units of application, and N is the total inductions of a

repair category. A complete listing of the non-zero estimated P values for the 602 NSA items are presented in Appendix D in decreasing value of estimated P value. Each individual record lists the cognizance code, NSN SMIC, nomenclature, repair category, units of application, total RFI engines, total demand, total requisitions, average requisition size, price, and P estimate.

The values ranged from a high of 9.90 to a low of 0.0067. Items with an estimated P of 1.0 are an indication that those parts are always replaced during the repair cycle. As stated previously, items that are always replaced should be stocked at the 100% level. A total of 35 repair parts or approximately 6% had a P value greater than 1.0. Repair parts with a P value in excess of 1.00 are a second indication that maintenance personnel may be ordering excess parts to meet future requirements.

Traditional ABC analyses of the historical demand data were conducted. The ABC concept is based on Pareto's Law or the 20-80 formula [Ref. 10]. It is an analytical management tool for focusing attention on specific inventory items. Normally the inventory items are split into categories of A, B, or C based upon the value of the inventory and usage of the items. The 20-80 formula stipulates that 20% of the line items represent 80% of the total inventory value. This 20% is then designated as Category A. A typical ABC classification is illustrated in Table 5.

TABLE 5
A Typical ABC Classification

Category	A	B	C
Items	20%	35%	45%
Inventory Value	80%	15%	5%

In the following analyses the number of line items and total demand were stratified in respect to the estimated P. Estimated P was chosen as the control parameter because it was assumed that a few parts with a high probability of demand should account for the largest demand percentage. The individual demand and line items distributions/ABC analyses are discussed below.

1. Line Item Analysis

The 567 line items which indicated replacement probability of less than 100% were analyzed. The distribution of the line items and the ABC graph are presented in Figures 4 and 5, respectively.

A review of Figure 4 indicates that the largest number of line items "167" had a probability of replacement of 0.12. Additionally, it can be seen that spikes in this distribution occurred at 0.05, 0.11, 0.18, 0.27, etc. From Figure 5 it can be seen that approximately 58% of the line items have an estimated P of less than 0.10. When the

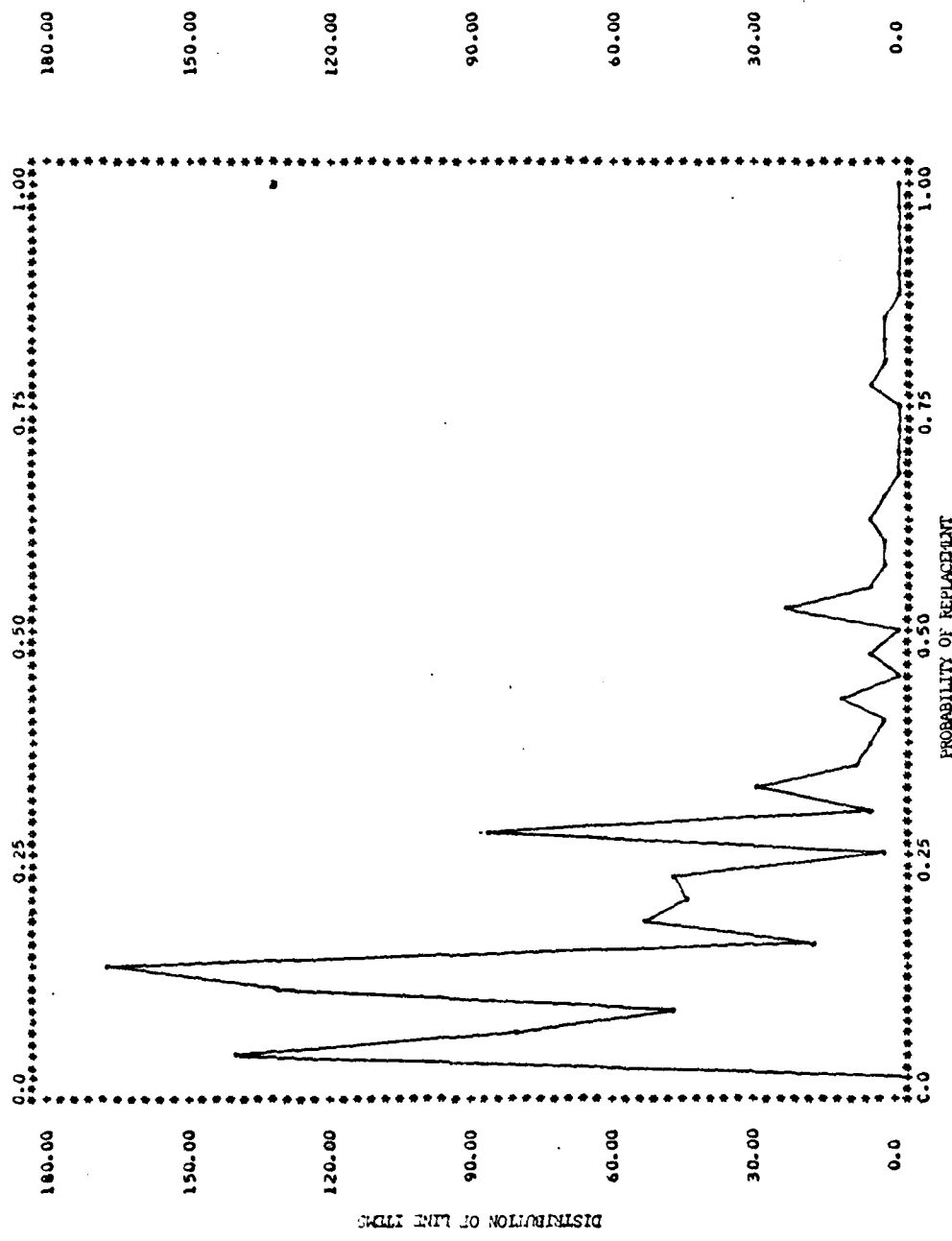


Figure 4: Distribution of Line Items

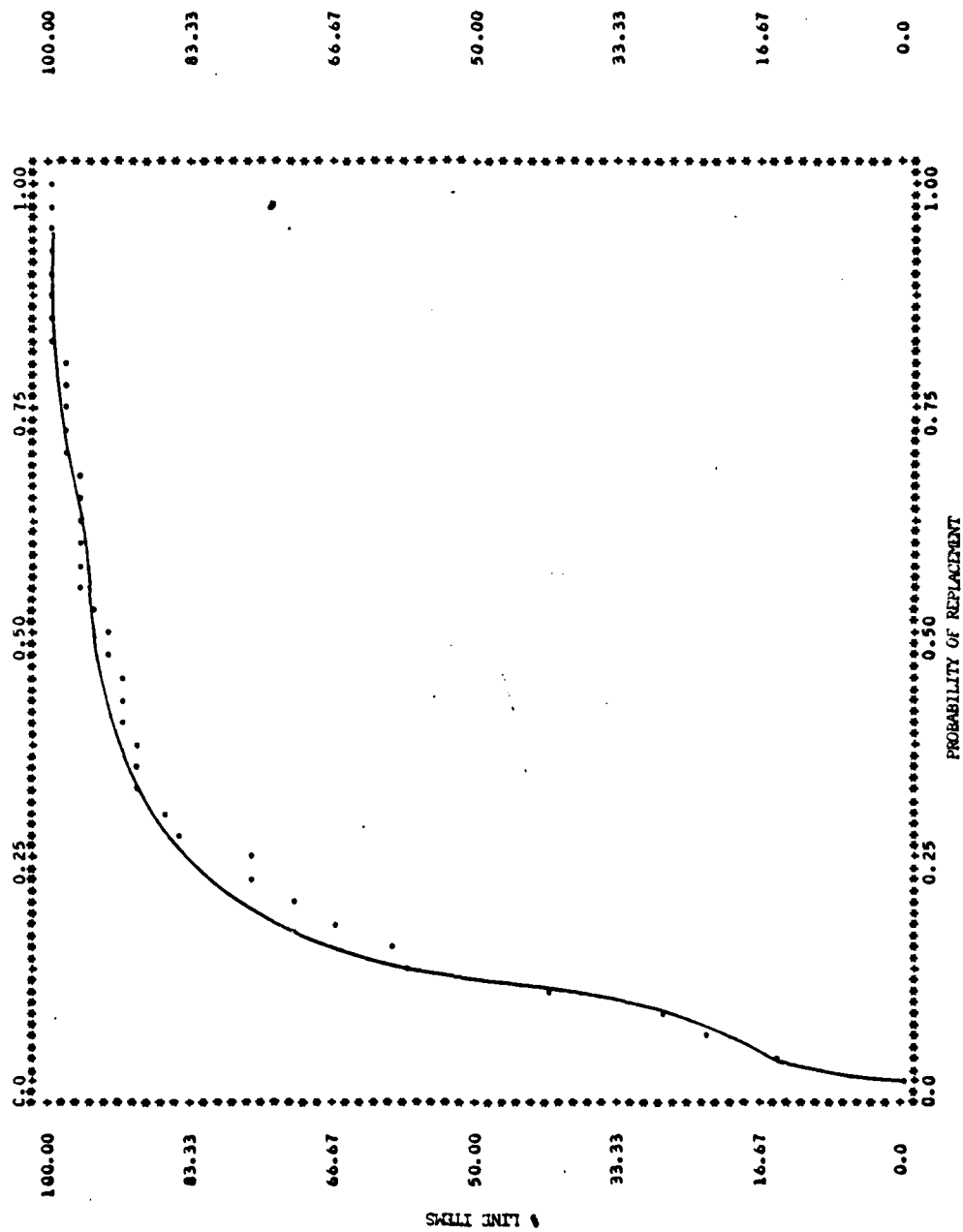


Figure 5: ABC Curve of Line Items

estimated P is increased to approximately 0.32 then almost 90% of the 567 line items are included.

2. Quantity Analysis

A total demand of 31,514 NSA repair parts were generated over the four quarters in support of the five rework categories. This total demand was spread over the 567 different line items which had an estimated P of less than 1.00 but greater than 0.00. The quantity demanded distribution and the associated ABC curve are presented in Figures 6 and 7.

From the distribution graph (Figure 6) it can be seen that the largest demand of 3,200 parts occurred at a P estimate of 0.075. As stated previously, it was expected that a high percentage of the demand would be generated by the items having the higher probabilities of replacement. This assumption is refuted by Figure 6. By comparing Figure 6 with Figure 4 it is apparent that the peaks in the distributions closely approximate each other. This pattern of increases appears to be a result of the units of application and the number of inductions in the various repair categories. A grouping of large units of applications occurs at each of the above peaks. At the 0.05 peak the units of application have values such as 52, 10, 22, 55, 27, and 79. The repair categories with the low induction rates but high units of application seem to be predominate at the high P

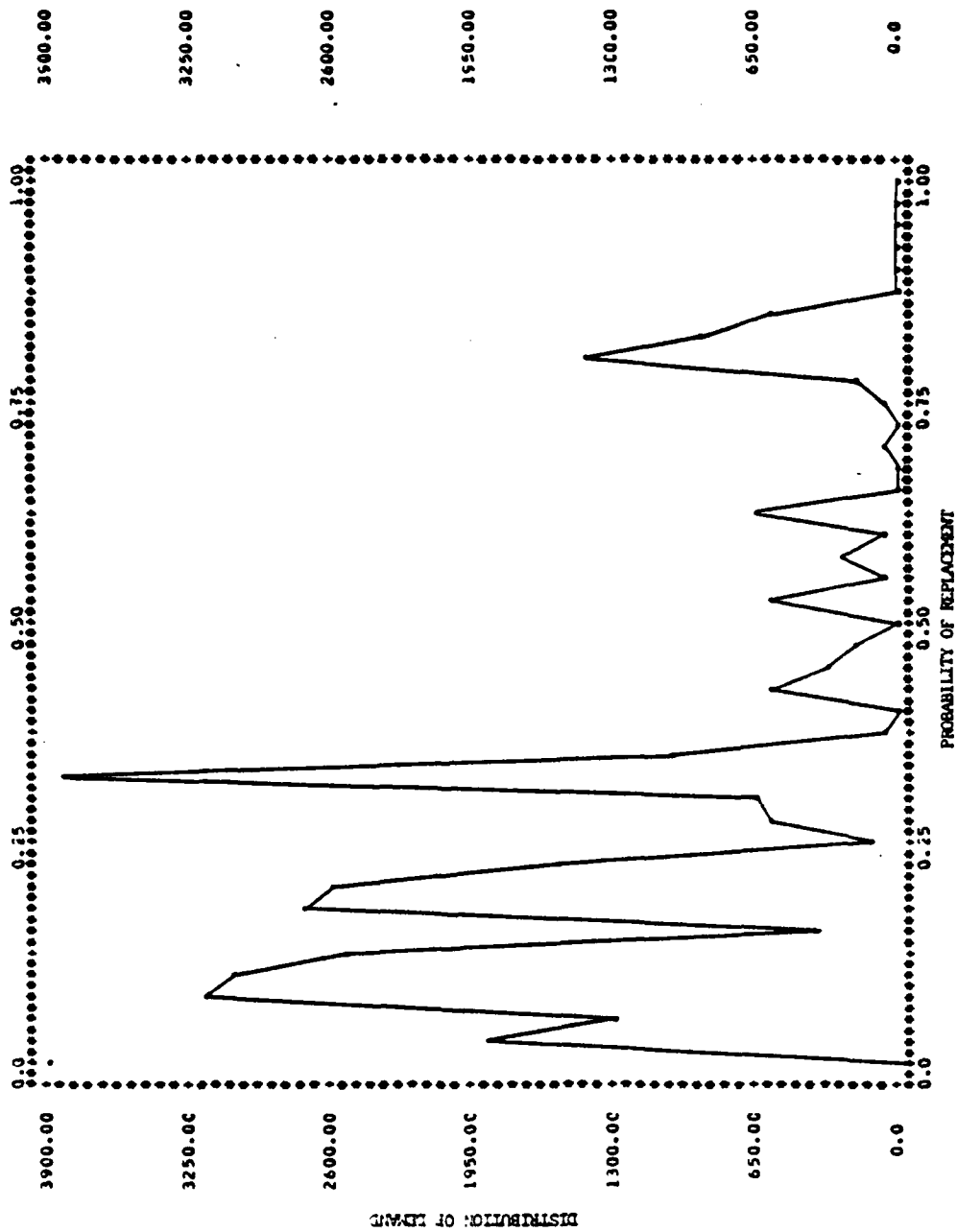


Figure 6: Distribution of Total Demand

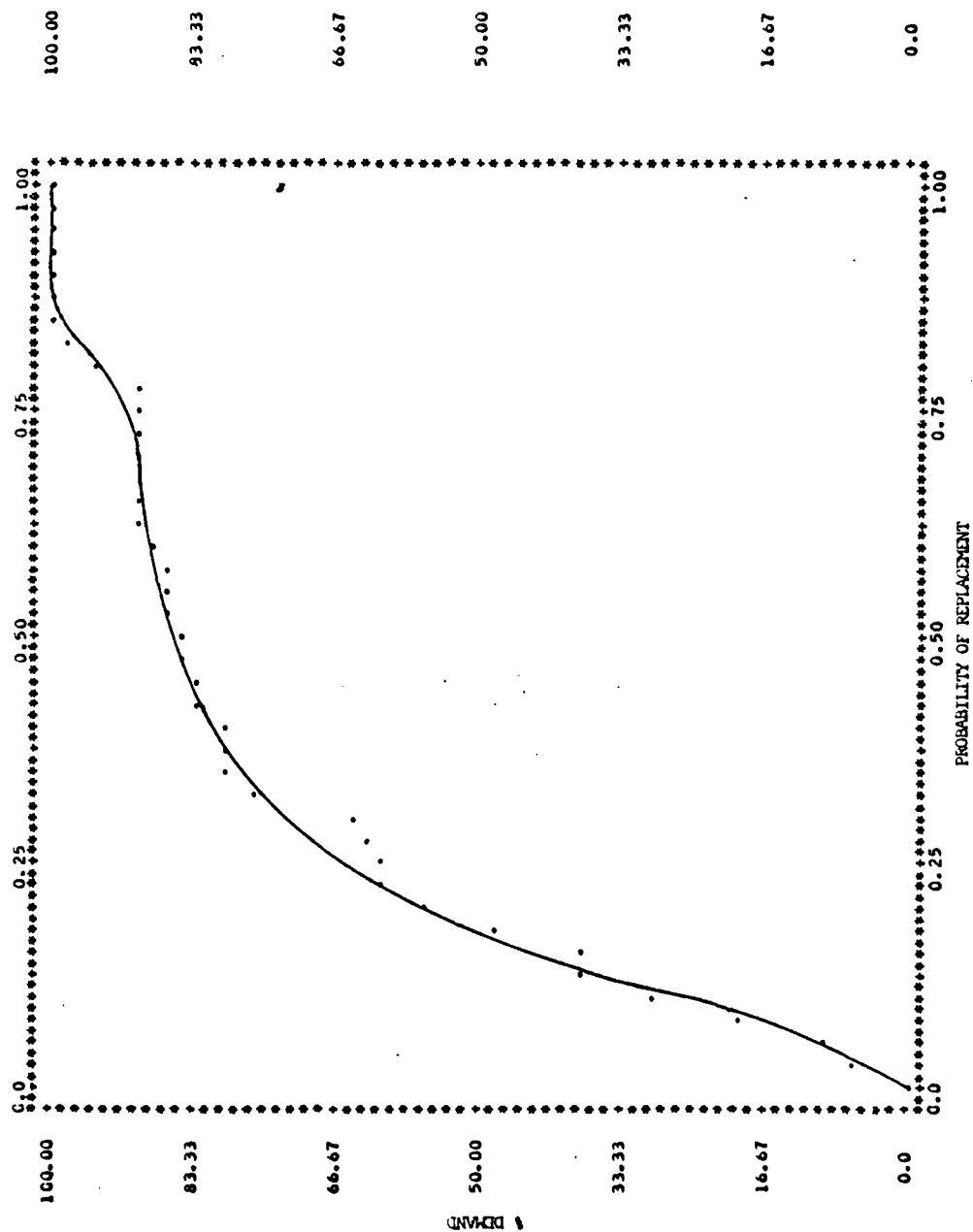


Figure 7: ABC Curve of Demand

values. The low P values are dominated by those TF34/Minor items having large units of application. That repair category also had the largest number of inductions.

3. Unit Price Analysis

A reasonable assumption is that the cost of an item is an indication of its reliability. Therefore a high cost part should be associated with a low P value. The line items were initially grouped in intervals of estimated P with the mean and standard deviation of the unit prices determined. These computed mean and deviation values are presented in Figures 8 and 9 respectively. The mean and standard deviation for all of the 567 items were \$320 and \$967, respectively. If only line items with an estimated P equal to or greater than 0.60 are utilized then the mean and standard deviation decrease to \$114 and \$167, respectively.

Regression techniques were utilized to determine the degree of correlation when price was regressed against estimated P value. A number of transformations were attempted in an effort to attain the best Coefficient of Determination, R^2 . In all of the transformations the R^2 was approximately zero. The regression results are presented in Table 6. For example, the formula for the log to base e transformation was:

$$\ln \text{ Price} = 3.87 + 0.0009P.$$

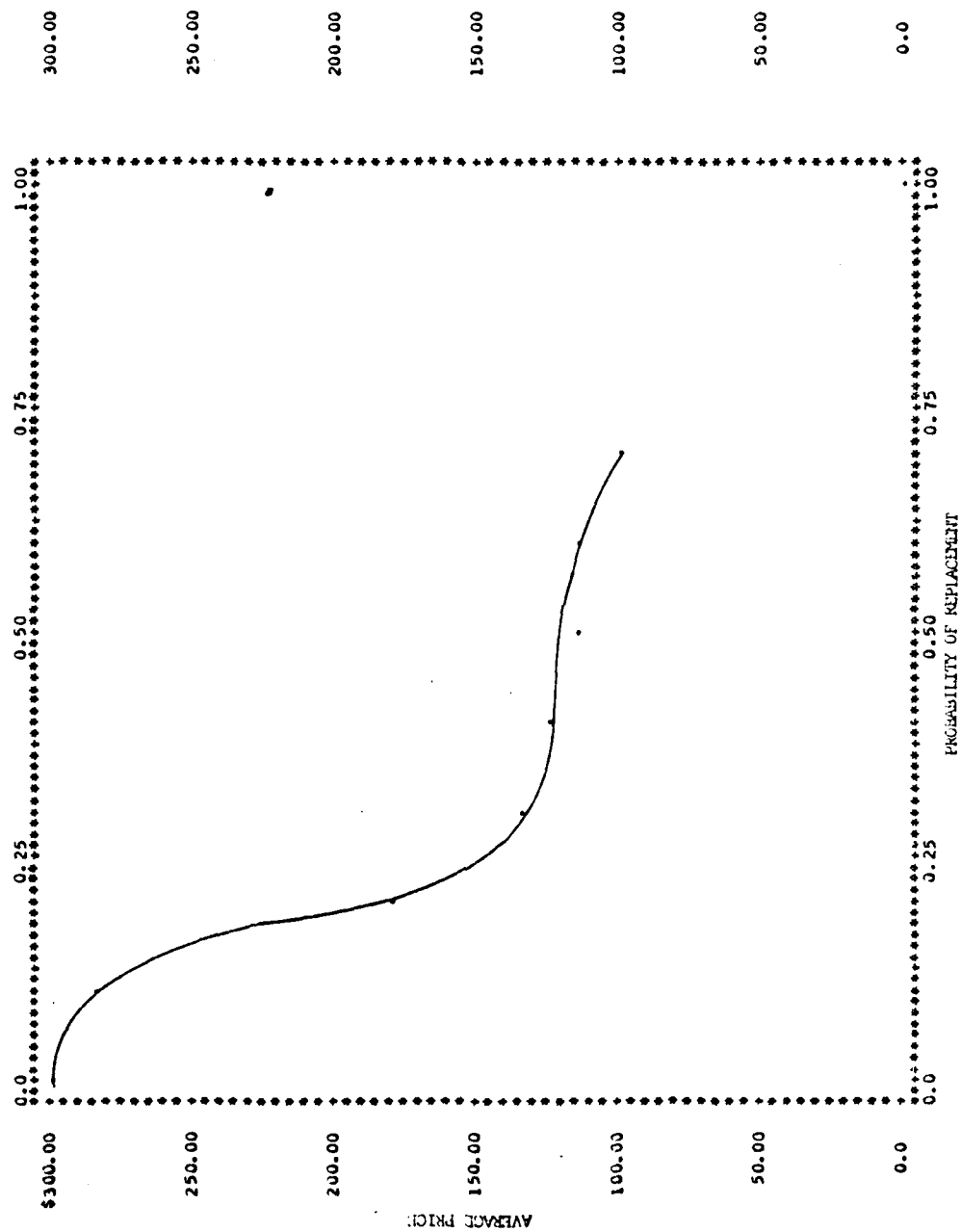


Figure 8: Average Price vs Estimated P

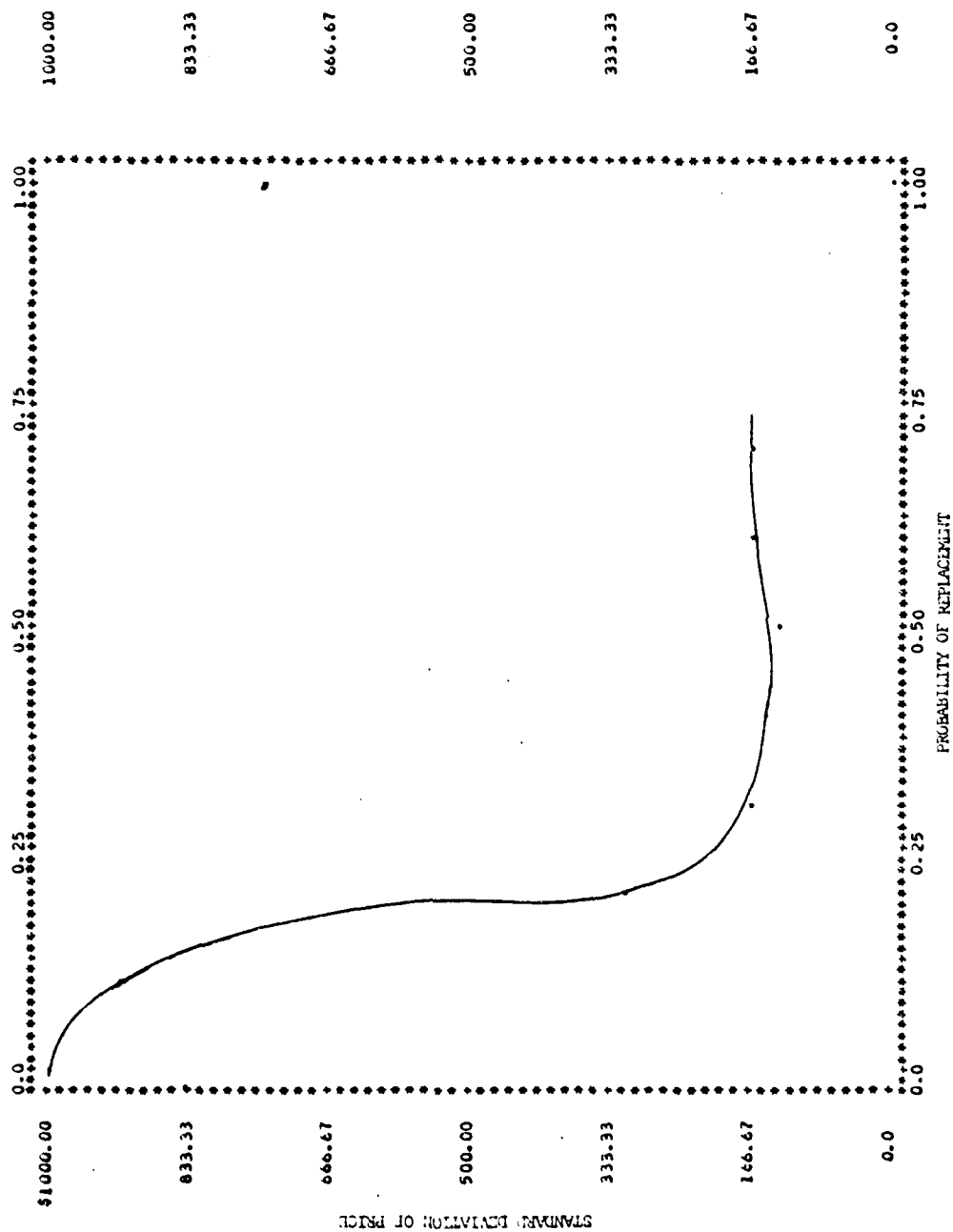


Figure 9: Standard Deviation of Price vs. Estimated P

The lack of a "fit" is due to the large variances in unit price, particularly at the lower estimated P values (see Figure 9).

TABLE 6
Unit Price Regression Data

Price Transformation	R ²
Price	0.004
Sqrt Price	0.002
1/Price	0.000
LogE Price	0.000
Log Price	0.000

4. P Value Accuracy

The actual P values for a given item are not known. As stated previously in Chapter II, the confidence intervals for actual P values are dependent upon both the size of the sample and the resulting estimated P values. The worst case for each of the five categories will occur when the estimated P is equal to 0.50.

For items in each repair category that had a units of application value of 1, the upper "u" and lower "l" limits of a 95% confidence interval are presented in Table 7 for estimated P values of 0.20 and 0.50. The largest sample size of 62 for the TF34-400/MIN repair category provides an interval from 0.37 to 0.63 when the estimated P is equal to 0.50. This means that we are 95% confident that the actual

TABLE 7
TF34 "P" Value Confidence Intervals

Category	N	0.20		0.50	
		l	u	l	u
TF34-100/MIN	11	0.02	0.56	0.20	0.80
TF34-100/MAJ*	4	0.02	0.61	0.16	0.84
TF34-DTE/MIN*	6	0.02	0.61	0.16	0.84
TF34-400/MIN	62	0.11	0.32	0.37	0.63
TF34-400/MAJ	10	0.02	0.56	0.18	0.82

*Limits are for N = 8.

P value lies in this interval. The bounds imply that the actual P value is within .13 of the estimated P value given a 95% confidence level. To reduce the width of this interval to a range of 0.45 to 0.55 the sample size must be increased to approximately 400.

Fortunately, the worse cast results apply to only a relatively few items as shown in Figure 4. The majority of the items have estimated P values of 0.27 or less. The confidence intervals based on an estimated P value of 0.20 are therefore more representative of a majority of the items. Finally, it is also true that large units of applications dominate the low P values. Therefore the confidence intervals can be expected to be less what is shown in the table, when the units of application m are greater than one. Because the accuracy of the estimated P values increases as

the size of the sample increases, the width of the confidence interval can be expected to decrease as more demand data is collected over time. A new improved estimated P value can be determined at the end of each quarter based on the aggregate demand data over all of the quarters to date.

D. INVENTORY COST DATA

Utility theory pertains to the intrinsic value of a parameter and its associated risks [Ref. 11]. Utility could therefore be defined as the value that the NARF assigns to an RFI engine in a given situation of possible work stoppages caused by insufficient inventory. A simple stocking procedure would be for NARF Alameda to maintain stock levels commensurate with the value of utility achieved. This intrinsic value of utility would be balanced against the inventory cost. For example, the cost to maintain a certain level of inventory such as the mean plus two standard deviations may be greater than the utility that is received by the NARF in the form of increased work stoppages.

Inventory cost estimates are provided in Table 8 based on the value of the inventory for the four quarters stocked to the expected demand, first deviation, second deviation, and 100% level. If the inventory was maintained at the expected demand of 6 units for a given repair part and repair category, then there is a fifty percent chance that seven or more units will be required that quarter and a work stoppage

TABLE 8
Inventory Cost Estimates

*(Thousands of Dollars)							
P Value	Mean*	S1*	Pct	S2*	Pct	100%*	Pct
0.007	\$2,718	\$3,632	33.6	\$4,536	66.9	\$22,531	728.9
0.100	2,314	2,909	25.7	3,493	51.0	9,041	290.7
0.200	1,743	2,026	16.2	2,299	31.9	5,279	202.9
0.300	1,360	1,498	10.1	1,627	19.6	3,661	169.2
0.400	372	427	14.9	474	27.4	666	79.0
0.500	260	297	14.1	326	25.4	397	52.8
0.600	181	191	10.6	215	18.5	245	35.4
0.700	145	157	8.5	166	14.3	185	27.8
0.800	64	66	3.5	69	6.4	78	21.0
0.900	2	3	11.1	3	11.1	3	11.1

will result. The 100% level is the maximum possible demand and is equal to the product of the number of inductions times the units per application of the line item and no work stoppage would result.

Costs to stock at the different levels were calculated using the estimated P values and the production schedule. The individual quarters were aggregated to provide an estimate of the total annual expenditures at the different levels of protection. The cost estimates in dollars and percentage of increase to achieve that level of protection above the mean are also presented in Table 8. P value in the table represents the smallest value for which a repair part would be stocked.

For example, if management determined that a part would not be stocked if its probability of being demanded in the quarter was less than 0.20, then the cost to stock all the items with a P value greater than 0.20 would be \$1,742,995 for the year. This equates to an average quarterly expenditure of \$435,748.

Because of budget constraints, it is reasonable to assume that NARF Alameda and NSC Oakland will not have unlimited funds available. Therefore, an arbitrary "not to exceed" unit cost of 1000 dollars might be assigned for an item in the RSS. If it costs 1200 dollars then it would not be requisitioned until after an actual demand was generated.

A cost comparison for stocking to the expected demand without a unit price constraint and with \$1000 a limit is presented in Figure 10. It can be seen that the limit has no appreciable effect until the probability of replacement drops below approximately 0.35. As Figures 8 and 9 show, the high cost items are strongly associated with low probabilities of replacement.

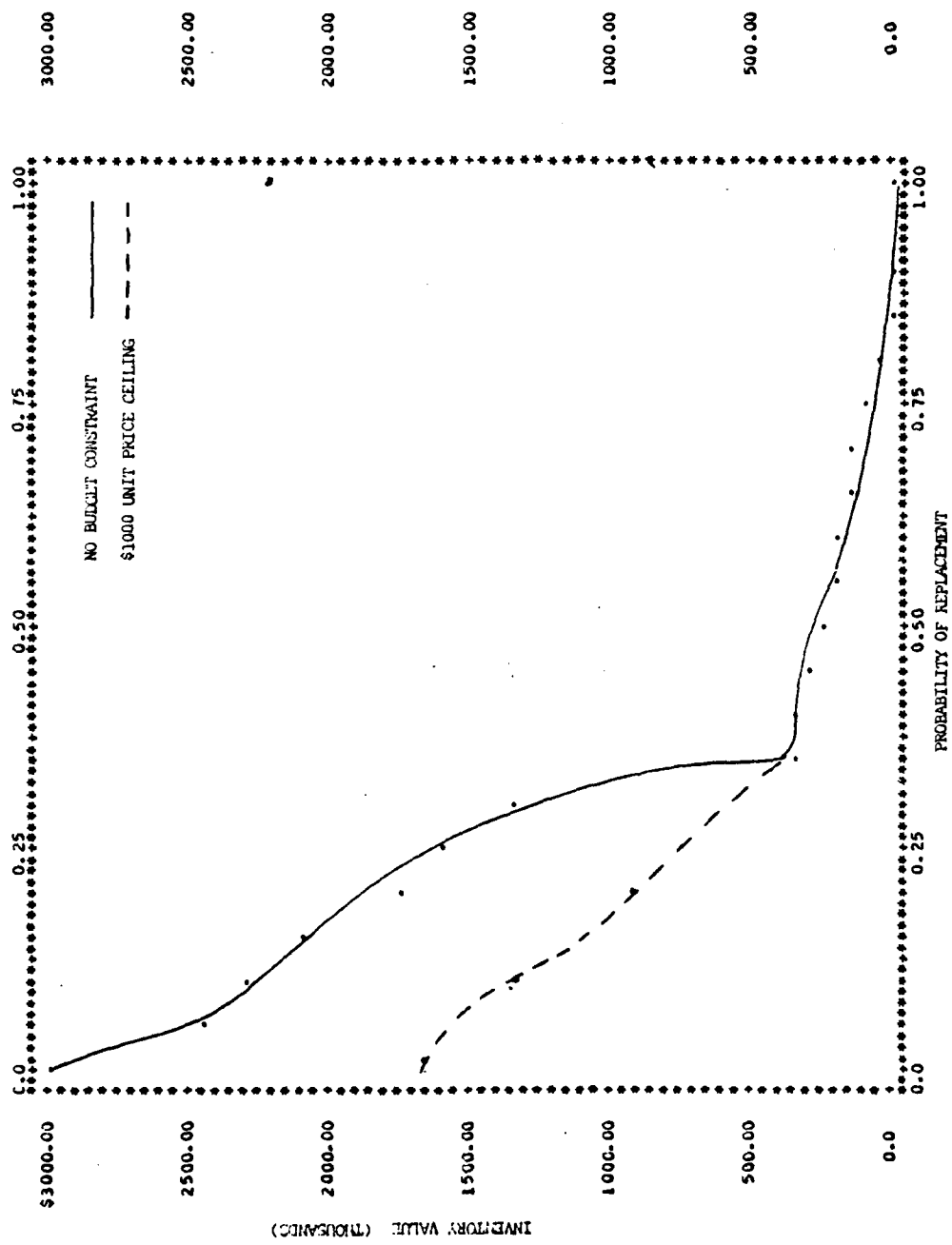


Figure 10: Inventory Value Comparison

IV. REPAIR PARTS INVENTORY MODEL

The proposed inventory model was described in Chapter II and is designed to balance the holding, processing, surplus, and shortage costs associated with a repair part. The total expected costs per quarter were described by equation (3) in Chapter II. An analysis of the parameters and their interactions are presented in this chapter.

A. INVENTORY PARAMETERS

The unit price C , processing cost C_p , holding cost C_h , and the probability of replacement P of a part are easy to determine. The price C of a part is available from either the Master Data File of the Uniform Inventory Control Point (UICP) system or the item manager. Historical data should be available on the processing costs to install an item in the RSS. The C_h value can be approximated by the product of the Holding Cost Rate (I) and C as in the UICP model. Presently the UICP system uses I equal to 0.21 per unit-year or 0.0525 per quarter for consumables (i.e., NSA items). The parameter P can be estimated from the historical demand records as has been done earlier in this thesis.

Since the value of C is fixed, the surplus cost KC can be made variable through the use of the K value. This quantity can be used as a measure of risk that NSC Oakland is willing

to accept in regards to having excess inventory at the end of a quarter. It is an approach for quantifying the financial impact that surplus items will have at the end of the quarter, especially if they are subsequently not demanded in the next quarter.

Three different methods of assigning K were analyzed. The first method was to have K be equal to an arbitrarily assigned value " a " which was then held constant ($K = a$). The second method allowed K to vary in proportion to the unit price of a part. The K factor was equal to the product of the value " a " and the unit price C ($K = aC$). For example, a \$1.00 consumable part may have no discernible effect on the RSS, whereas a \$5000 part could prevent the stocking of sufficient inventory of other parts and thereby result in excessive work stoppages. The third method had K vary inversely to the population P value ($K = a - aP$). In this case, a part with a low probability of demand such as 0.05 would be assigned a higher K value than a part with a P value of 0.75. This allows for additional consideration of the fact that a part with a low probability of replacement stands a good chance of not being required in the next quarter. As the probability of demand approaches 1.00, the K value would approach zero reflecting the fact that the chance of a surplus is approaching zero.

The shortage cost C_s is not readily available. As stated previously, it represents the additional costs incurred as a

result of a work stoppage. It should represent the manhours spent to backrob, manhours consumed by maintenance personnel to change job tasks, and the intrinsic cost of delaying the availability of a RFI asset to the fleet. Data should be available in which the cannibalization manhours spent can be determined for the individual assets. The manhours spent on changing job tasks could possibly be approximated by utilizing the standard manhours allowed for setting up a task. The intrinsic cost of not having an RFI asset cannot be determined explicitly at the present, but should be a measure of aircraft readiness degradation.

B. SHORTAGE COST VS UNIT PRICE

The relationship between the unit price of a part and the shortage cost associated with the asset were analyzed for each of the above methods of assigning the K parameter. This provided a basis for comparing the effects of the different K factors on the optimal quantity y in relation to the unit price and shortage cost values. The parameters C_h , C_p , and P were defined as the product of 0.21 times C divided by four, \$1.00, and \$50.00, respectively.

Figure 11 presents the unit shortage cost values versus the unit price of a part when K is equal to 0.25, 0.50, and 1.00. The linear curve corresponds to when the optimal quantity of y is equal to the expected demand nmP (i.e., the right hand side of equation (4) is equal to 0.50). If a

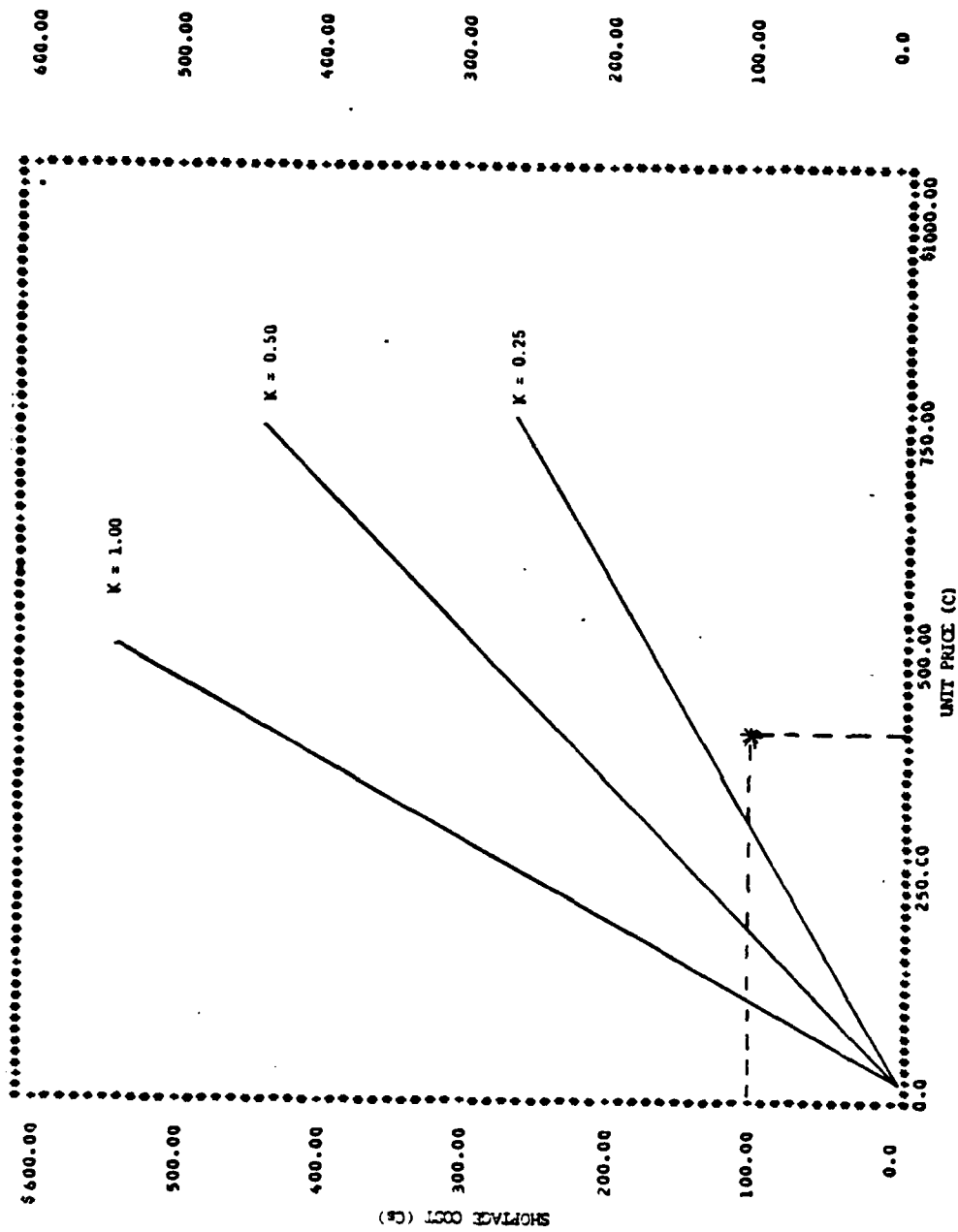


Figure 11: Unit Shortage Cost vs Unit Price when Optimal Y
Is the Expected Demand and K Is Constant

point is above the curve then it indicates that the part should be stocked at a level greater than the expected demand. For example, if the NARF assigned a shortage cost of \$100 to the TF34-400/Minor repair category, the cost of a repair part was equal to \$400, and K was equal to 0.25 then the part should be stocked to a level less than the expected demand. The example point is shown in Figure 11.

Figure 12 presents the second method of varying K in proportion to the unit price when y is the mean demand. In this example the constant " a " is assigned the values of 0.00025, 0.0005, and 0.001. For the first " a " value, K varies from 0 to 0.025 (the end-points correspond to the $K = 0.25$ curve of Figure 11). It can be seen that the shortage cost and the unit price assume a non-linear relationship. As in Figure 11, the points above a curve correspond to the optimal quantity y being greater than the expected demand. The same shortage cost and unit price values in the previous example now result in the optimal quantity y being greater than the expected demand when K goes from 0 to 0.025.

The third method of assigning the K value is presented by Figure 13. Since K is now a function of the P value, curves for P values of 0.10, 0.30, 0.50, 0.70, and 0.90 are depicted. Although curves for values of " a " larger than 0.25 are not shown, their impact would be similar to the shifts experienced in Figures 11 and 12.

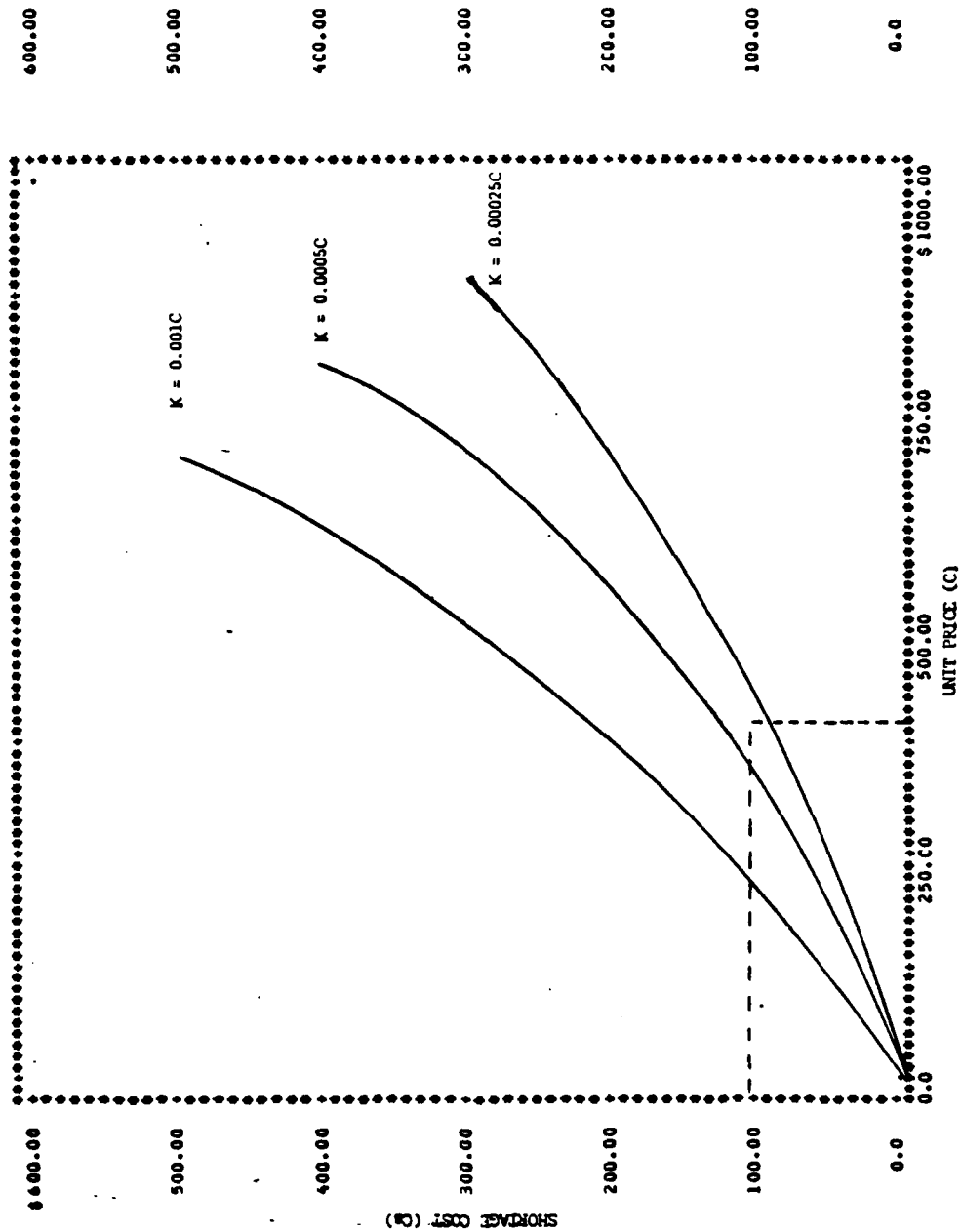


Figure 12: Unit Shortage Cost vs Unit Price when Optimal Y Is the Expected Demand and K Is Proportional to Unit Price

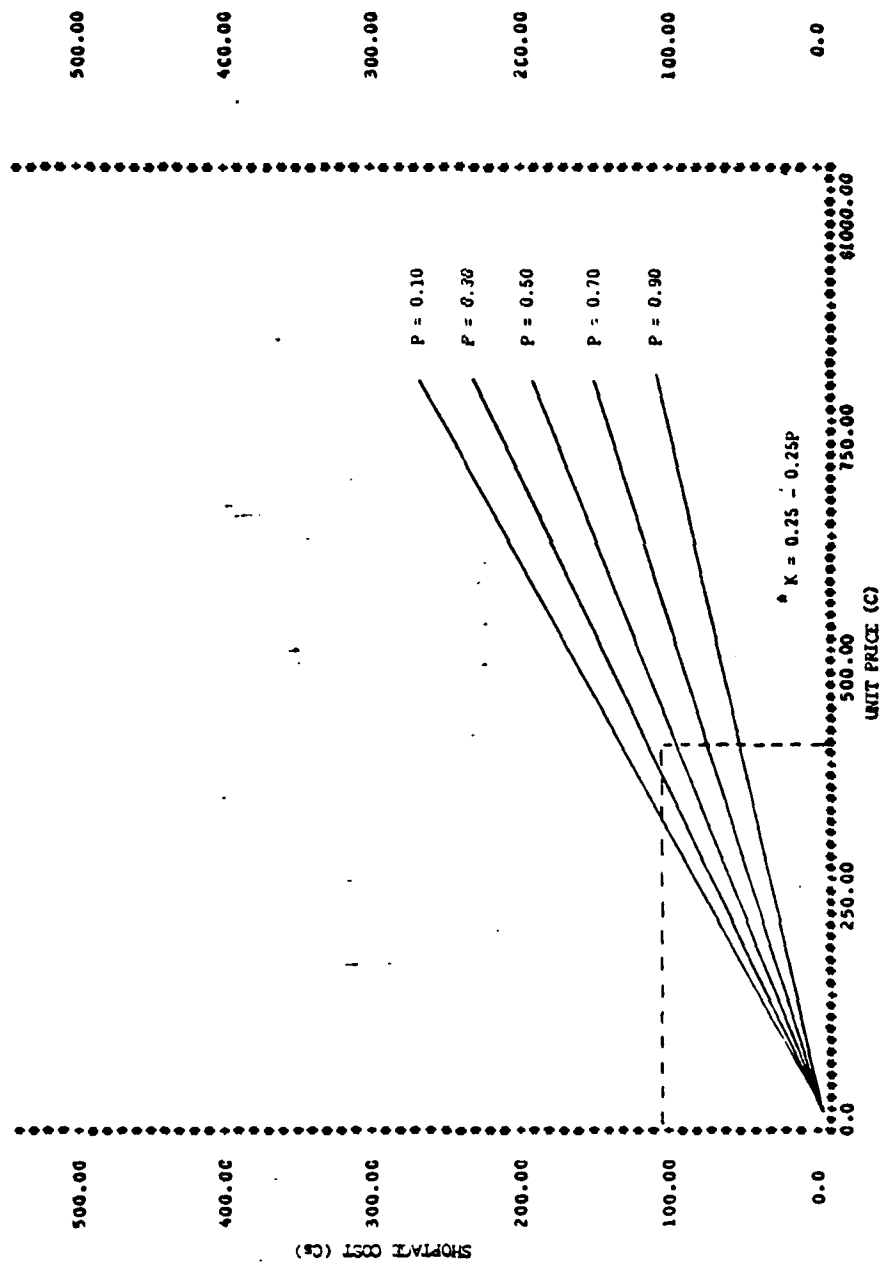


Figure 13: Unit Shortage Cost vs Unit Price when Optimal Y Is the Expected Demand and K Is Proportional to the Probability of Demand

C. OTHER INFLUENCES

Although a detailed analysis of them is beyond the scope of this thesis, two additional parameters are worthy of mention when influences of K and Cs are being considered. They include the complexity of the repairable asset and the induction quantity.

1. Repairable Asset Complexity

A large number of different assets are inducted for rework by NARF Alameda throughout the quarter. These inductions can range from a major end item such as an aircraft or an engine to a repairable component such as a generator or a fuel control.

It is reasonable to assume that the shortage and/or surplus costs associated with a major asset such as an aircraft will be different from those of a fuel control. A major end item may have a higher shortage cost because of its greater impact on the workload if a work stoppage is experienced.

2. Induction Quantity

A final factor which should be considered in the establishment of K and Cs values is the quantity of an asset to be inducted. For example, if only one asset is inducted per quarter the impact on the expected number of surplus parts will be much less than if ten assets had been inducted. A similar behavior will occur in the expected number of shortage of parts. As a consequence, K and Cs should

incorporate some increasing function of the number of anticipated inductions.

Additionally, knowledge of the anticipated need for a part in a future quarter should be incorporated in the K and possibly the Cs values. Usually there is some information known about the expected workload in the quarter following the period being scheduled at the workload conference. If an item can be used in the following quarter then the impact of a surplus at the end of the quarter being scheduled will not be as great as when no demands are expected.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The NARF located at NAS Alameda is presently implementing a variation of a MRP system. This system will provide management with the capability to project quarterly supply requirements based on the production schedule.

As discussed in Chapter II, the traditional MRP system is dependent upon the Master Production Schedule, Bill of Materials, and Inventory File. The production schedule is derived from a forecast of the expected requirements for an end product or products. The MRP logic assumes that once a production schedule is decided upon the material requirements can be accurately determined because of their dependency to the schedule.

Rework introduces a new parameter to the classic MRP approach because every repair part that is identified in the bill of materials is not necessarily required each time an asset is inducted into rework. In a rework process such as at NARF, only the parts that are defective are required to RFI the end product.

One goal of this thesis was to generate the probability of replacement values for the TF34 engine repair parts. It was assumed that the NARF's quarterly production schedule of N products creates a demand for a repair part that can be

modeled by the Binomial Distribution. Because of this uncertainty in demand, a support inventory is appropriate.

A proposed inventory model was developed by McMasters and is reviewed in the final sections of Chapter II. This inventory model provides a means for balancing the costs associated with inventory shortages and surpluses.

Chapter III contains the analysis of the engine repair data for 1980. There were large fluctuations in the number of engines reworked from quarter to quarter. Differences were also noted in the number of parts required to support the TF34-100 and 400 engines even though the depth of repair classification was the same. Additionally, increasing the depth of repair did not necessarily increase the number of line items required for that repair.

The units of applications and demand history files were utilized to generate the probability of replacement values for NSN identified parts which are procured with the NSA. The probabilities were assumed to be computable from the ratio of the total demand and the product of the units of application and total inductions. The calculated values ranged from 9.90 to a low of 0.0067. The probabilities equal to 1.00 indicate that the repair part is always replaced during rework. Values in excess of 1.00 are a result of excess material being ordered. A majority of the line items had an estimated P value of less than 0.27 or

greater than 0.75 with the accuracy increasing as the values approached either 0.00 or 1.00.

It was initially assumed that the repair parts with a high P value would generate a large percentage of the demand. But this assumption was refuted by the results of the analysis. The repair categories with a low induction rate but high units of application dominated the high P values; whereas the TF34 minor with the high induction rate prevailed at the low P values.

Regression analysis failed to identify any correlation between a part's unit price and its probability of replacement. Large variances in the unit price were found throughout the range of P values, with particularly large variances at the low P values. The average price of a repair part did decrease from approximately \$300 to \$120 as the probability increased from 0.01 to 0.70.

Inventory investment cost projections were determined based on stocking to the expected demand or mean, the first and second standard deviations beyond the mean, and at the 100% level. The total investment costs at the different levels of inventory began to greatly increase when the estimated P values dropped below 0.35. These costs could be greatly reduced by setting a ceiling such as \$1000 on the unit price of a repair part to be placed in inventory. This was particularly effective at the low estimated P values.

Chapter IV presented parametric analyses of the surplus and shorage costs when an optimal quantity of an item was placed in inventory. The surplus cost was a function of a factor designated as K and the unit price C of a repair part. Three shortage versus unit price curves were generated for the following proposed forms of the K factor:

1. $K = A$,
2. $K = AC$,
3. $K = A - AP$,

where A is a constant, C is the unit price, and P is the probability of replacement.

B. CONCLUSIONS

The following conclusions were reached from the analyses conducted in this thesis.

1. The implementation of an MRP system at NARF Alameda is important for projecting the quarterly supply requirements.
2. The P values are distorted by maintenance personnel ordering repair parts in excess of the units of application.
3. Except for the TF34 minor repair category, the one-year time period was too short to provide adequate sample sizes for attaining accurate estimates of the P values.
4. The lack of any correlation between the unit price and the probability of replacement was a result of the large variances in the unit prices.
5. The high unit prices are normally associated with the low estimated P values.

6. The pattern of peaks in the quantity and line items distributions is a result of the units of application and repair category induction rate.
7. The effectiveness of the Inventory Model can be increased if the actual shortage costs were known.
8. In absence of the actual shortage and surplus values, the shortage cost versus unit price curves can provide management with a tool for balancing the associated costs.
9. The actual form of the surplus cost factor K may be dependent on more than just unit price or probability of replacement.

C. RECOMMENDATIONS

This thesis is a preliminary step in the implementation phase of the NARF's MRP system. It concentrated on the TF34-100/400 engines. Analyses of a similar nature are needed on other components overhauled by the NARF. However, the work on the other components must await the development of their respective bills of materials. Relative to the TF34 engine the following recommendations for further analysis are made.

1. The MRP logic must be able to identify any repair part that is ordered with the actual induction that it is to be utilized on. It must also prevent personnel from ordering material in excess of the units of application.
2. The accuracy of the P values can be increased by having these values updated on a continual basis with the demands aggregated over several years to increase the sample size.
3. The actual costs of a work stoppage should be determined prior to the utilization of the Repair Part Inventory Model.

4. Further analysis of the surplus cost K factor should be conducted in order to adapt it to a form which is desirable to management.

APPENDIX A
NARF ALAMEDA DISPOSITION CODES

1. A Analytic Rework
2. BT Bench Test
3. BZ Beyond Economical Repair
4. CR Controlled Rework
5. CT Check and Test
6. FV Facility Verification
7. L Leave On
8. MZ Missing
9. NA Not Applicable
10. ND No Document
11. NI Not-Incorporated (TDC)
12. NM Negotiated Replacement (Missing)
13. NZ Non-Standard (Remove/Replace)
14. OZ Obsolete
15. PR SDLM/Depot Level Maintenance Rework
16. R Overhaul
17. RZ Remove for Accessibility
18. S Scrap
19. SP Structural Sampling Program
20. X Remove for Access/Temporarily Re-install

APPENDIX B

SAMPLE RECORD FROM UNITS PER APPLICATION FILE

PART NUMBER	CCG	NSN	SMIC	NOMFN	UA
5026T42G02	RM	2840-00-030-9220	SN	SECT NR, S12	6
6017T00P03		2840-00-030-9221	TB	SHAFT, HPT	
6021T36G03	RM	2840-00-030-9222	SN	SECT NR, S1	20
2682072	GZ	5360-00-030-9630		SPRING	22
52-01312-1		5360-00-030-9631		SPRING	11
52-01156-2		5360-00-030-9676		SPRING	11
52-01267-1		5360-00-030-9678		SPRING	11
3020T52P05	GZ	5365-00-030-9682		RING	11
390501		4820-00-032-1740		SEAL	11
4020T13P01		2840-00-032-2716	TB	SHIM, LD	11
3024T53P01		2840-00-032-2741	TB	WEIGHT	22
3024T53P02	RM	2840-00-032-2742	SN	WEIGHT	22
3024T53P03		2840-00-032-2758	TB	WEIGHT	22
3024T53P05		2840-00-032-2759	TB	WEIGHT	22
4020T37P02		2840-00-032-2761	TB	WEIGHT	22
4020T70P01		2840-00-032-2834	TB	WEIGHT	22
4019T38P01	RM	2840-00-032-2856	SN	SEAL	11
3023T57P01	RM	2840-00-032-2857	SN	WEIGHT	44
3023T57P03	RM	2840-00-032-2898	SN	WEIGHT	44
3023T57P04		2840-00-032-2937	TB	WEIGHT	20
6016T58G08	RM	2840-00-032-2959	SN	SECT NR, S3	21
3033M36G01	RM	2840-00-032-3318	SN	CONNECTOR	11
7017M71G02	RM	2840-00-032-3319	SN	CONNECTOR	11
5033M33G03	RM	2840-00-032-3321	SN	CONNECTOR	11
J360P07	GZ	5365-00-032-3415		PLUG	11
J478P03	GZ	5365-00-032-3430		INSERT	26
52-01266-2	RM	2840-00-032-3540	SN	COVER	11
4420-522		2840-00-032-3545		LEVER ASSY	11
52-01310-1	RM	2840-00-033-3084	SN	PISTON	11
52-01265-2		2840-00-033-3085		COVER, ACCE	11
914619	RZ	4332-00-033-6873	SN	KEY, O/H	11
38-79004-00		4332-00-033-6877		SEAL	21
394519	RM	4332-00-033-6902	SN	RING ASSY	11
32-62315-00	RM	4332-00-033-6906	SN	PLATE ASSY	11
32-53005-10	RM	4332-00-033-6938	SN	HEAD ASSY	11
24-4560C-01	RM	4332-00-033-6941	SN	GEAR TOR AS	21
32-62315-00	RM	4332-00-033-6942	SN	PLATE ASSY	21
24-4550C-00	RM	4332-00-033-6953	SN	GEAR TOR AS	21
5024T16P01		2840-00-033-7115		PISTON	11
6020T24G02	RD	2840-00-033-7236	SN	PAVEL	16
6016T63P04		2840-00-033-7247	TB	BLADE, 4	15
6016T62P04	RM	2840-00-033-7250	SN	BLADE, 3	58
6021T11P01	RM	2840-00-033-7254	SN	BLADE, STG1	77
6021T17P01		2840-00-033-7256	TB	BLADE, STG7	77
6021T17P02	RM	2840-00-033-7257	SN	BLADE, SP7	77
6021T19P01		2840-00-033-7266	TB	BLADE, STG9	79
6021T24P01		2840-00-033-7271	TB	BLADE, STG1	92
6021T24P02	RM	2840-00-033-7276	SN	BLADE, SPI4	77
5026T33P01	RM	2840-00-033-7316	SN	VALE, STG3	69
5026T34P01		2840-00-033-7328	TB	VALE, STG4	76
5026T35P01	RM	2840-00-033-7336	SN	VALE, STG5	78
6021T20P01		2840-00-033-7350	TB	BLADE, STG1	85
6021T20P02	RM	2840-00-033-7352	SN	BLADE, SPI0	77
6021T21P01		2840-00-033-7359	TB	BLADE, STG1	79
6021T21P02	RM	2840-00-033-7361	SN	BLADE, SPI1	79
6018T50G03	RM	2840-00-033-7368	SN	SEAL, .6 LPT	22
6018T50G05		2840-00-033-7369	TB	SEAL, .6 LPT	22
6018T51G02	RM	2840-00-033-7380	SN	SEAL, .6 LPT	22
6018T51G05		2840-00-033-7381	TB	SEAL, .6 LPT	22
5023T67P01		2840-00-033-7382	TB	SEAL	22

APPENDIX C

SAMPLE RECORD FROM THE DEMAND HISTORY FILE

COG	NSN	RPR CATEGORY	QTR	UI	DEMAND	REQN	PRICE
1R	2640000309221	TF34/100/MAJ	3	EA	1	1	6240.00
1R	2640000309221	TF34/400/MIN	4	EA	1	1	6240.00
1R	2640000309222	TF34/100/MAJ	2	EA	20	1	133.00
1R	2640000309222	TF34/100/MAJ	3	EA	19	1	133.00
1R	2640000309222	TF34/100/MAJ	4	EA	20	1	133.00
1R	2640000309222	TF34/400/MIN	2	EA	20	1	133.00
1R	2640000309222	TF34/400/MIN	3	EA	40	2	133.00
1R	2640000309222	TF34/400/MIN	4	EA	20	1	133.00
1R	2640000322716	TF34/100/MAJ	2	EA	1	1	161.00
1R	2640000322759	TF34/100/MAJ	4	EA	100	1	1.90
1R	2640000322856	TF34/400/MIN	4	EA	2	2	663.00
9C	43200003369C6	TF34/400/MAJ	4	EA	1	1	131.07
9C	4320000336941	TF34/400/MAJ	2	EA	2	1	138.64
9C	4320000336941	TF34/400/MAJ	4	EA	2	2	175.82
9C	4320000336941	TF34/400/MIN	3	EA	4	2	138.64
9C	4320000336953	TF34/400/MAJ	4	EA	2	2	105.44
9C	4320000336953	TF34/400/MIN	2	EA	2	1	105.44
9C	4320000336953	TF34/400/MIN	3	EA	7	4	105.44
9C	4320000336953	TF34/400/MIN	5	EA	2	2	105.44
1R	2640000337247	TF34/400/MIN	4	EA	42	1	46.00
1R	2640000337250	TF34/400/MIN	4	EA	72	1	42.50
1R	2640000337267	TF34/400/MIN	5	EA	8	1	14.50
1R	2640000337271	TF34/400/MIN	4	EA	99	1	11.00
1R	2640000337352	TF34/100/MIN	4	EA	30	1	8.10
1R	2640000337352	TF34/400/MIN	4	EA	5	1	11.00
1R	2640000337361	TF34/100/MIN	4	EA	30	1	9.50
1R	2640000337361	TF34/400/MIN	4	EA	5	1	10.50
1R	2640000337369	TF34/100/MAJ	2	EA	2	1	225.00
1R	2640000337369	TF34/100/MAJ	3	EA	2	1	225.00
1R	2640000337369	TF34/400/MAJ	5	EA	2	1	256.00
1R	2640000337369	TF34/400/MIN	4	EA	2	4	225.00
1R	2640000337361	TF34/100/MAJ	2	EA	2	1	245.00
1R	2640000337361	TF34/100/MAJ	3	EA	2	2	245.00
1R	2640000337381	TF34/400/MAJ	2	EA	2	2	245.00
1R	2640000337381	TF34/400/MAJ	5	EA	1	1	204.00
1R	2640000337381	TF34/400/MIN	4	EA	8	1	245.00
1R	2640000337475	TF34/100/MAJ	3	EA	4	2	298.00
1R	2640000337475	TF34/400/MAJ	3	EA	4	2	298.00
1R	2640000337475	TF34/400/MAJ	4	EA	2	2	293.00
1R	2640000337475	TF34/400/MAJ	5	EA	2	3	293.00
1R	2640000337475	TF34/400/MIN	2	EA	5	3	305.00
1R	2640000337475	TF34/400/MIN	3	EA	6	3	298.00
1R	2640000337475	TF34/400/MIN	4	EA	2	3	298.00
1R	2640000337489	TF34/100/MAJ	2	EA	2	1	237.00
1R	2640000337489	TF34/100/MAJ	3	EA	2	1	237.00
1R	2640000337489	TF34/100/MIN	4	EA	2	1	237.00
1R	2640000337489	TF34/400/MIN	5	EA	2	1	273.00
1R	2640000337489	TF34/400/MAJ	2	EA	2	1	237.00
1R	2640000337489	TF34/400/MAJ	3	EA	2	1	237.00
1R	2640000337489	TF34/400/MAJ	4	EA	4	2	237.00
1R	2640000337489	TF34/400/MIN	5	EA	10	2	237.00
1R	2640000337489	TF34/400/MIN	2	EA	9	5	237.00
1R	2640000337489	TF34/400/MIN	4	EA	8	4	237.00
1R	26400003375C0	TF34/100/MAJ	2	EA	2	1	234.00
1R	26400003375C0	TF34/100/MAJ	3	EA	2	1	234.00
1R	26400003375C0	TF34/100/MIN	4	EA	2	1	234.00
1R	26400003375C0	TF34/100/MIN	5	EA	2	1	234.00
1R	26400003375C0	TF34/100/MIN	2	EA	2	1	273.00
1R	26400003375C0	TF34/400/MAJ	2	EA	2	1	234.00

PROBABILITY REPLACEMENT "P" VALUES

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QC	432000005331160	BLADE	400MIN	8	63	8	1	8.00	18.33	0.0161
IR	284000005331160	HOUSING	400MIN	1	1	1	1	1.00	113.00	0.0161
IR	284000005331160	SPINNER	400MIN	1	1	1	1	1.00	771.00	0.0161
IR	284000005331160	SHAFT	400MIN	1	1	1	1	1.00	778.00	0.0161
IR	284000005331160	NOZZLE 3	400MIN	1	1	1	1	1.00	84.00	0.0161
QC	473000005331160	ELBOW	400MIN	2	2	2	2	2.00	12.68	0.0161
IR	284000005331160	HOUSING	400MIN	1	1	1	1	1.00	78.00	0.0161
IR	284000005331160	HOUSING	400MIN	1	1	1	1	1.00	131.00	0.0161
IR	284000005331160	HOUSING	400MIN	1	1	1	1	1.00	83.00	0.0161
IR	284000005331160	PLUG	400MIN	1	1	1	1	1.00	15.00	0.0161
IR	284000005331160	SLINGER	400MIN	1	1	1	1	1.00	111.00	0.0161
IR	284000005331160	VALVE AS	400MIN	1	1	1	1	1.00	147.00	0.0161
IR	284000005331160	TUBE	400MIN	1	1	1	1	1.00	32.50	0.0161
IR	284000005331160	RETAINER	400MIN	1	1	1	1	1.00	41.50	0.0161
QC	302000005331160	GEAR SHAF	400MIN	1	1	1	1	1.00	1210.00	0.0161
QC	302000005331160	GEAR	400MIN	1	1	1	1	1.00	1140.00	0.0161
QC	302000005331160	COUPLING	400MIN	1	1	1	1	1.00	161.97	0.0161
QC	302000005331160	GEAR SHAF	400MIN	1	1	1	1	1.00	1960.00	0.0161
QC	311000005331160	BEARING	400MIN	1	1	1	1	1.00	93.24	0.0161
IR	284000005331160	SPINNER	400MIN	1	1	1	1	1.00	1470.00	0.0161
IR	284000005331160	ELEMENT	400MIN	1	1	1	1	1.00	204.00	0.0161
QC	534000005331160	TURNSUCK	400MIN	4	4	4	4	4.00	18.03	0.0161
IR	311000005331160	BEARING	400MIN	1	1	1	1	1.00	80.00	0.0161
IR	311000005331160	HOSE	400MIN	1	1	1	1	1.00	131.00	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	23.00	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	37.50	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	34.00	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	41.50	0.0161
QC	284000005331160	GEAR SHAF	400MIN	1	1	1	1	1.00	121.00	0.0161
QC	312000005331160	BUSHING	400MIN	1	1	1	1	1.00	1070.00	0.0161
QC	312000005331160	BUSHING	400MIN	1	1	1	1	1.00	5.01	0.0161
IR	312000005331160	BUSHING	400MIN	1	1	1	1	1.00	12.41	0.0161
IR	312000005331160	BUSHING	400MIN	1	1	1	1	1.00	14.00	0.0161
IR	482000005331160	VALVE	400MIN	1	1	1	1	1.00	39.50	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	38.50	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	23.50	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	23.50	0.0161
QC	534000005331160	CLIP	400MIN	64	64	64	64	64.00	0.28	0.0161
IR	284000005331160	SPOOL, FW	400MIN	1	1	1	1	1.00	10500.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	30.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	41.50	0.0161
IR	284000005331160	COUPLING	400MIN	1	1	1	1	1.00	32.50	0.0161
QC	534000005331160	PTV	400MIN	64	64	64	64	64.00	1.86	0.0161
QC	534000005331160	NUT ASSY	400MIN	64	64	64	64	64.00	41.21	0.0161
QC	534000005331160	NUT	400MIN	64	64	64	64	64.00	29.89	0.0161
QC	534000005331160	NUT ASSY	400MIN	64	64	64	64	64.00	0.14	0.0161
IR	534000005331160	RING	400MIN	1	1	1	1	1.00	4.00	0.0161
QC	534000005331160	NUT ASSY	400MIN	2	2	2	2	2.00	67.11	0.0161
IR	311000005331160	BEARING	400MIN	1	1	1	1	1.00	747.00	0.0161
IR	284000005331160	HOUSING	400MIN	1	1	1	1	1.00	2480.00	0.0161
IR	284000005331160	RUNNER	400MIN	1	1	1	1	0.33	384.00	0.0161
IR	284000005331160	DISK, I	400MIN	1	1	1	1	1.00	3960.00	0.0161
IR	284000005331160	SPACER	400MIN	1	1	1	1	1.00	14.93	0.0161
QC	534000005331160	ELEMENT	400MIN	12	12	12	12	12.00	26.50	0.0161
QC	534000005331160	NUT	400MIN	12	12	12	12	12.00	1.93	0.0161
IR	284000005331160	BRACKET	400MIN	1	1	1	1	1.00	1.81	0.0161
IR	284000005331160	BRACKET	400MIN	1	1	1	1	1.00	17.50	0.0161
QC	534000005331160	PLUG, ELE	400MIN	1	1	1	1	1.00	26.00	0.0161
IR	284000005331160	RESTRICT	400MIN	1	1	1	1	1.00	46.41	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	365.00	0.0161
IR	472000005331160	HOSE	400MIN	1	1	1	1	1.00	34.00	0.0161
IR	472000005331160	VALVE	400MIN	1	1	1	1	1.00	37.50	0.0161
IR	482000005331160	COUPLING	400MIN	1	1	1	1	1.00	174.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	3020.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	11.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	14.50	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	11.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	8.90	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	11.00	0.0161
IR	284000005331160	BLADE, LK	400MIN	1	1	1	1	1.00	14.50	0.0161

12	284000C1697472	TB	BLADE	ST	400MAJ	79	10	86	1	86.00	18.50	0.1089
12	284000C1697476	TB	BLADE	ST	400MAJ	85	10	92	1	92.00	12.00	0.1087
12	284000C1697476	TB	BLADE	ST	400MAJ	89	10	92	1	92.00	12.00	0.1079
12	284000C1697476	TB	BLADE	ST	400MAJ	92	10	99	1	99.00	13.00	0.1074
12	284000C17375C2	TB	PLATE	AS	400MAJ	24	10	25	1	25.00	1.98	0.1042
12	432000C0336953	TB	GEAR	CTOR	400MAJ	1	2	1	1	1.00	131.07	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	2	2	2	2	2.00	71.39	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	3	2	2	2	2.00	256.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	4	2	2	2	2.00	182.40	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	5	2	2	2	2.00	249.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	6	2	2	2	2.00	25.69	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	7	2	2	2	2.00	42.31	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	8	2	2	2	2.00	1080.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	9	2	2	2	2.00	222.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	10	2	2	2	2.00	368.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	11	2	2	2	2.00	69.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	12	2	2	2	2.00	174.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	13	2	2	2	2.00	698.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	14	2	2	2	2.00	18.33	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	15	2	2	2	2.00	16.32	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	16	2	2	2	2.00	82.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	17	2	2	2	2.00	106.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	18	2	2	2	2.00	177.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	19	2	2	2	2.00	677.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	20	2	2	2	2.00	648.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	21	2	2	2	2.00	3.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	22	2	2	2	2.00	91.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	23	2	2	2	2.00	10.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	24	2	2	2	2.00	95.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	25	2	2	2	2.00	83.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	26	2	2	2	2.00	850.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	27	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	28	2	2	2	2.00	108.99	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	29	2	2	2	2.00	79.92	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	30	2	2	2	2.00	32.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	31	2	2	2	2.00	38.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	32	2	2	2	2.00	10.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	33	2	2	2	2.00	41.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	34	2	2	2	2.00	47.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	35	2	2	2	2.00	2180.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	36	2	2	2	2.00	270.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	37	2	2	2	2.00	278.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	38	2	2	2	2.00	111.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	39	2	2	2	2.00	150.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	40	2	2	2	2.00	229.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	41	2	2	2	2.00	217.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	42	2	2	2	2.00	25.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	43	2	2	2	2.00	28.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	44	2	2	2	2.00	35.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	45	2	2	2	2.00	104.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	46	2	2	2	2.00	25.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	47	2	2	2	2.00	30.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	48	2	2	2	2.00	32.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	49	2	2	2	2.00	69.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	50	2	2	2	2.00	107.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	51	2	2	2	2.00	123.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	52	2	2	2	2.00	36.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	53	2	2	2	2.00	42.50	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	54	2	2	2	2.00	56.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	55	2	2	2	2.00	52.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	56	2	2	2	2.00	70.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	57	2	2	2	2.00	54.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	58	2	2	2	2.00	76.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	59	2	2	2	2.00	64.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	60	2	2	2	2.00	36.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	61	2	2	2	2.00	39.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	62	2	2	2	2.00	32.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	63	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	64	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	65	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	66	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	67	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	68	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	69	2	2	2	2.00	33.00	0.1000
12	432000C0336953	TB	GEAR	CTOR	400MAJ	70	2	2	2	2.00	33.00	0.1000

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1R	284000012186358	SN	VALVE, INL	100MAJ	38	11	38.00	53.00	0.00	0.00
1R	284000012186358	SN	ELEMENT	100MAJ	11	11	1.00	204.00	0.00	0.00
1R	284000012186358	SN	PISTON	100MAJ	11	11	1.00	5.60	0.00	0.00
1R	284000012186358	SN	RECYCLER	100MAJ	11	11	1.00	99.00	0.00	0.00
1R	284000012186358	SN	SHROUD, S	100MAJ	11	11	1.00	273.00	0.00	0.00
1R	284000012186358	SN	SECTOR, S	100MAJ	11	11	1.00	99.00	0.00	0.00
1R	284000012186358	SN	SECTOR, S	100MAJ	11	11	1.00	108.00	0.00	0.00
1R	284000012186358	SN	SKID, S	100MAJ	11	11	1.00	7490.00	0.00	0.00
1R	284000012186358	SN	BEARING, S	100MAJ	11	11	1.00	762.00	0.00	0.00
1R	284000012186358	SN	NUT	100MAJ	11	11	1.00	49.50	0.00	0.00
1R	284000012186358	SN	STRAP	100MAJ	11	11	1.00	20.09	0.00	0.00
1R	284000012186358	SN	STEVIS	100MAJ	11	11	1.00	32.68	0.00	0.00
1R	284000012186358	SN	COUPLING	100MAJ	11	11	1.00	25.50	0.00	0.00
1R	284000012186358	SN	DTCT, CH	100MAJ	11	11	1.00	1.70	0.00	0.00
1R	284000012186358	SN	RING	100MAJ	11	11	1.00	22.50	0.00	0.00
1R	284000012186358	SN	SECTOR, S	100MAJ	11	11	1.00	164.00	0.00	0.00
1R	284000012186358	SN	NUT	100MAJ	11	11	1.00	4.60	0.00	0.00
1R	284000012186358	SN	RING	100MAJ	11	11	1.00	46.93	0.00	0.00
1R	284000012186358	SN	WASHER	100MAJ	11	11	1.00	123.44	0.00	0.00
1R	284000012186358	SN	KEY	100MAJ	11	11	1.00	18.50	0.00	0.00
1R	284000012186358	SN	DTCT, CH	100MAJ	11	11	1.00	34.30	0.00	0.00
1R	284000012186358	SN	COUPLING	100MAJ	11	11	1.00	24.22	0.00	0.00
1R	284000012186358	SN	WASHER	100MAJ	11	11	1.00	979.00	0.00	0.00
1R	284000012186358	SN	SEAL	100MAJ	11	11	1.00	97.14	0.00	0.00
1R	284000012186358	SN	VANNE, STG	100MAJ	11	11	1.00	81.11	0.00	0.00
1R	284000012186358	SN	VANNE, STG	100MAJ	11	11	1.00	85.07	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	106.16	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	207.80	0.00	0.00
1R	284000012186358	SN	TUBER	100MAJ	11	11	1.00	109.29	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	39.20	0.00	0.00
1R	284000012186358	SN	CABLE	100MAJ	11	11	1.00	548.58	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	32.28	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	52.58	0.00	0.00
1R	284000012186358	SN	RUNNER	100MAJ	11	11	1.00	384.00	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	38.40	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	177.62	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	41.57	0.00	0.00
1R	284000012186358	SN	TER	100MAJ	11	11	1.00	94.03	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	35.13	0.00	0.00
1R	284000012186358	SN	TUBER	100MAJ	11	11	1.00	51.02	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	25.78	0.00	0.00
1R	284000012186358	SN	TUBER	100MAJ	11	11	1.00	48.07	0.00	0.00
1R	284000012186358	SN	BRACKET	100MAJ	11	11	1.00	398.00	0.00	0.00
1R	284000012186358	SN	KIT, NO. 1	100MAJ	11	11	1.00	340.00	0.00	0.00
1R	284000012186358	SN	KIT, NO. 3	100MAJ	11	11	1.00	340.00	0.00	0.00
1R	284000012186358	SN	KIT, NO. 5	100MAJ	11	11	1.00	222.40	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	171.35	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	71.00	0.00	0.00
1R	284000012186358	SN	SUPP. RT	100MAJ	11	11	1.00	1077.99	0.00	0.00
1R	284000012186358	SN	CABLE	100MAJ	11	11	1.00	103.00	0.00	0.00
1R	284000012186358	SN	IGNITOR	100MAJ	11	11	1.00	590.00	0.00	0.00
1R	284000012186358	SN	KIT, C PLG	100MAJ	11	11	1.00	16.50	0.00	0.00
1R	284000012186358	SN	TUBE	100MAJ	11	11	1.00	1.06	0.00	0.00
1R	284000012186358	SN	PACKING	100MAJ	11	11	1.00	353.36	0.00	0.00
1R	284000012186358	SN	HOSE	100MAJ	11	11	1.00	32.33	0.00	0.00
1R	284000012186358	SN	VANE, STG	100MAJ	11	11	1.00	309.71	0.00	0.00
1R	284000012186358	SN	SEGMENT	100MAJ	11	11	1.00	20.00	0.00	0.00
1R	284000012186358	SN	NUT	100MAJ	11	11	1.00	25.61	0.00	0.00
1R	284000012186358	SN	REDUCER	100MAJ	11	11	1.00	16.94	0.00	0.00
1R	284000012186358	SN	REDUCER	100MAJ	11	11	1.00	13.90	0.00	0.00
1R	284000012186358	SN	NTPLER	100MAJ	11	11	1.00	17.50	0.00	0.00
1R	284000012186358	SN	BLADE, LK	100MAJ	11	11	1.00	68.74	0.00	0.00
1R	284000012186358	SN	KIT, FILT	100MAJ	11	11	1.00	5.45	0.00	0.00
1R	284000012186358	SN	ELSON	100MAJ	11	11	1.00	273.00	0.00	0.00
1R	284000012186358	SN	SHROUD, S	100MAJ	11	11	1.00	275.00	0.00	0.00
1R	284000012186358	SN	SHROUD, S	100MAJ	11	11	1.00	38.00	0.00	0.00
1R	284000012186358	SN	DETECTOR	100MAJ	11	11	1.00	241.67	0.00	0.00
1R	284000012186358	SN	PLUG	100MAJ	11	11	1.00	280.00	0.00	0.00
1R	284000012186358	SN	SHROUD, S	100MAJ	11	11	1.00	280.00	0.00	0.00

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